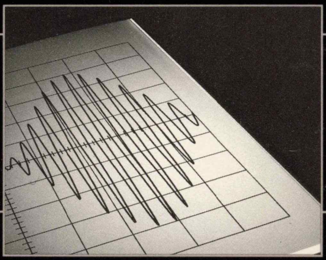
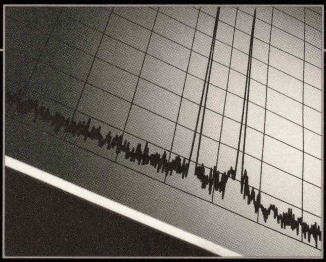
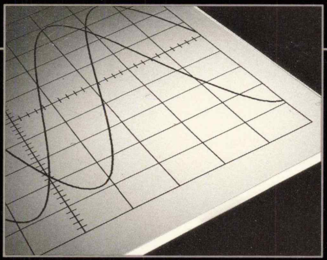
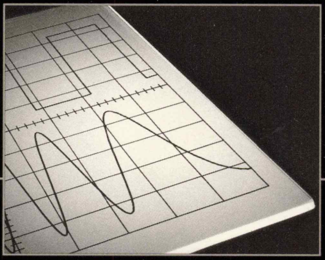
PRODUCT NOTE 3326A-1
INTRODUCTORY OPERATING GUIDE TO THE HP 3326A TWO-CHANNEL SYNTHESIZER









INTRODUCTION

Two or more signals are commonly required in ATE systems, intermodulation and signalling applications and for generation of a phase offset. In the past, two separate signal sources were commonly required to produce these signals. In many cases, additional equipment such as a phase meter or oscilloscope was needed if calibration was important. The use of two separate sources increased equipment complexity and added to measurement difficulty. The Hewlett-Packard 3326A is a solution to these problems in a single instrument. The HP 3326A combines two synthesized sources to form a synergistic pair that solves these problems and provides the user with a powerful set of new measurement capabilities and convenience.

This introductory operating guide describes the basic capabilities and operation of the HP 3326A, addresses many applications and illustrates ways in which this Two-Channel Synthesizer can help simplify measurements.

Chapter 1 describes the main features while Chapter 2 familiarizes the reader with the controls and connectors of the front and rear panels. Chapters 3, 4 and 5 describe basic keystrokes and applications for the Two-Channel, Two-Tone, and Two-Phase modes of operation, respectively. A complete listing of error codes can be found in Appendix A.

TABLE OF CONTENTS

1. THE HP 3326A

THE HP 3326A

What Is The HP 3326A?

The HP 3326A is a Two-Channel Synthesizer, which combines two dc-to-13 MHz synthesizers into one instrument as shown in the simplified block diagram, Figure 1.1. It provides the user with a better solution to today's complex signal needs by reducing the number of instruments required while providing new high performance capabilities and measurement versatility. Microprocessor control of both synthesizers maintains simultaneous control of each source while simplifying operation. The microprocessor also provides internal and external calibration, coordinated sweeping of both outputs, and HP-IB* capabilities.

• What's Unique About The HP 3326A?

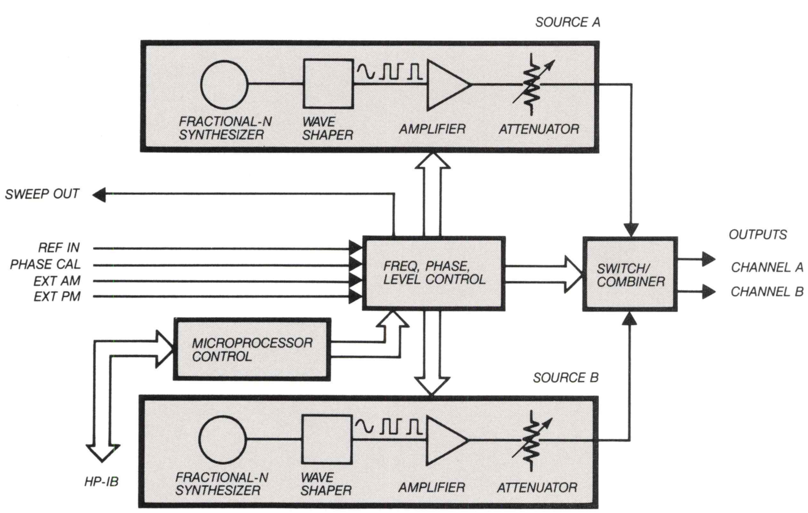
First, the HP 3326A has four modes of operation which determine the relationship between the Channel A and B outputs; Two-Channel, Two-Tone, Two-Phase and Pulse. The Channel A and B outputs can be combined into a single composite output signal at Channel A in the first three modes, or Channel B can be used to internally amplitude or phase modulate Channel A in the Two-Channel mode. The Pulse mode is derived from the Two-Phase mode and operation is similar.

Sweep capabilities include phase continuous sweep of both channels as well as a powerful new Discrete Sweep for random frequency sweeps. The HP 3326A provides 1 μHz resolution below 100 kHz and 1 mHz from 100 kHz to 13 MHz. Amplitude resolution is 0.01 dB. Let's look at some of these unique features in more detail.

• A Clean Signal Source

Sinusoidal signals have harmonic and spurious content of less than −80 dBc below +13 dBm and 100 kHz as shown in Figure 1.2. The spurious content is −70 dBc at maximum output level and frequency. Integrated residual phase noise (with Option 001) is specified at −66 dBc for a 30 kHz band centered on a 10 M Hz carrier (excluding a ±1 Hz band centered about the carrier). Internal sinusoidal channel isolation is −80 dB so that channel crosstalk effects are minimized for excellent signal integrity.

Figure 1.1
Simplified HP 3326A block diagram.



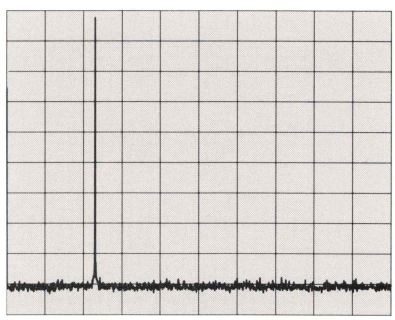


Figure 1.2
Low harmonic and spurious levels.

*HP-IB; not just IEEE-488, but the hardware, documentation and support that delivers the shortest path to a measurement solution.

The Two-Channel Mode

In the Two-Channel mode, the HP 3326A functions as two separate dc-to-13 MHz synthesized sources, with independent frequency, amplitude and waveform control for Channels A and B as shown in Figures 1.3a and 1.3b. Either or both channels can be swept separately with independent start and stop frequencies. Modulation capabilities include external AM and PM for each channel. In addition, internal AM and PM are available for Channel A using the Channel B output as a calibrated modulation source. The Two-Channel mode is particularly useful in applications requiring two independent signals with a synchronous relationship to a common frequency reference. Chapter 3 describes Two-Channel operation and applications in more detail.

The Two-Tone Mode

The Two-Tone mode is useful for intermodulation distortion testing and signaling applications as covered in Chapter 4. In this mode, the output frequencies of both the Channel A and B signals can be set from dc to 13 MHz, but the frequency difference between the two signals must be within 100 kHz of each other.

An example is illustrated in Figure 1.4a and 1.4b. Both the Channel A and Channel B frequencies can be independently swept within this relationship. Setting the Channel A frequency (with sweep off) automatically alters the frequency of Channel B to maintain a constant offset in the Two-Tone mode.

This signal pair can be produced with one signal at each channel output, or combined into one composite signal at the Channel A output connector. Signal amplitudes and waveforms can be independently selected as in the Two-Channel mode and external modulation can be applied.

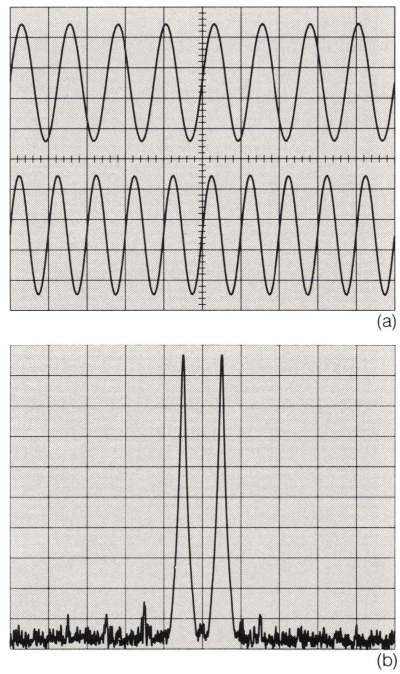


Figure 1.4
(a) Time domain and (b) frequency domain of two tracking signals using the Two-Tone mode.

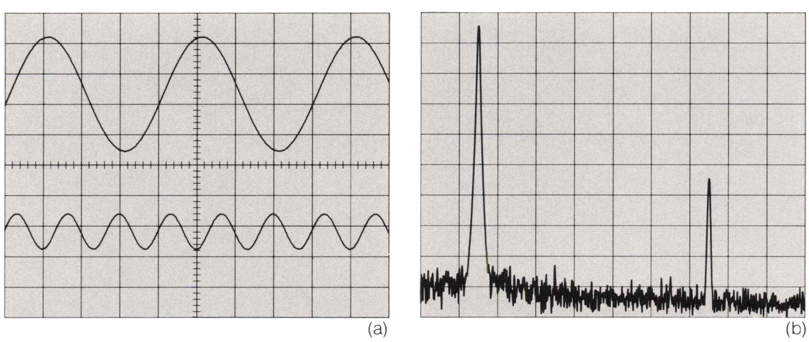
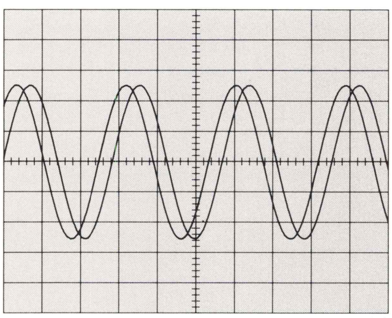


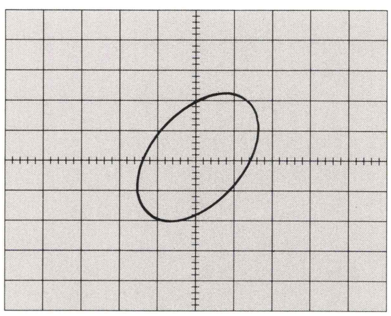
Figure 1.3
(a) Time domain and (b) frequency domain of two signals using the Two-Channel mode.

The Two-Phase Mode
This mode provides a calibrated phase offset between two signals at the same frequency as illustrated in Figures 1.5a and 1.5b. As with the other HP 3326A modes, the individual signals at the Channel A and B outputs have independently selectable amplitudes and waveforms.

The phase offset is calibrated and eliminates the need for external measurement instruments such as a phasemeter, counter-timer, or oscilloscope commonly required when using two single sources. Internal and external calibration is also provided for accuracies up to 0.2 degree with 0.01 degree resolution. A multiphase calibration feature allows the user to extend operation to three or more phases by adding additional HP 3326A's. Multiple phases are commonly required in phased array applications as discussed in Chapter 5.



(a)

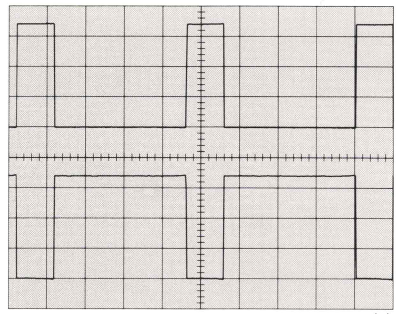


(b)

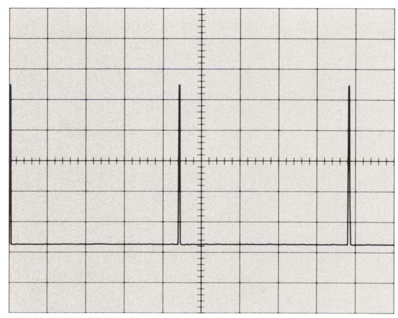
Figure 1.5
(a) Time domain and (b) Lissajous pattern representation of two signals using the Two-Phase mode.

The Pulse Mode
In the Pulse mode, the HP 3326A produces a precision pulse at the Channel A output and its complement at the Channel B output. This mode is similar to the Two-Phase mode and offers the same degree of accuracy, resolution and stability. Pulse width accuracy is 1% of the period with a resolution of 0.1% of the period.

The width of the pulse is determined by the duty cycle which can be set from 1% to 99% (mimimum width 20 ns) and remains constant as the frequency is changed or swept. The HP 3326A produces pulses with ≤5% overshoot and ≤15 ns rise and fall times. The amplitudes of both outputs can be individually selected for additional versatility. Examples of these capabilities are shown in Figures 1.6a and 1.6b.



(a)



(b)

Figure 1.6
(a) A pulse and it's complement in the Pulse mode, and (b) Pulses as narrow as 20 ns can be generated with the HP 3326A.

Waveform Functions

The HP 3326A allows the user to independently select sine wave or square wave functions at the Channel A and B outputs in the Two-Channel, Two-Tone and Two-Phase modes. A dc offset can be added to either of the outputs in any these modes as well as the Pulse mode. The maximum peak amplitude of the ac plus dc signal is ± 5 volts (± 20 volts with the High-Voltage Output option).

A combination of sine, square or pulse waveforms with a dc offset is convenient for interfacing directly to devices requiring a bias offset or for elevating an ac signal above ground for TTL applications. The HP 3326A can generate a dc-only output signal on either channel by simply selecting the DC Output function. In this case, the dc value will be that of the dc offset level. Figures 1.7a through 1.7d are examples of some of the waveforms possible with the HP 3326A.

• *Combining Two Signals*

An internal combiner can be used to sum the two output signals together to produce one composite signal at the Channel A output connector. This feature applies to the Two-Channel, Two-Tone and Two-Phase modes. With the combiner activated a dc offset is not allowed. Figures 1.8a and 1.8b show two signals before and after being combined.

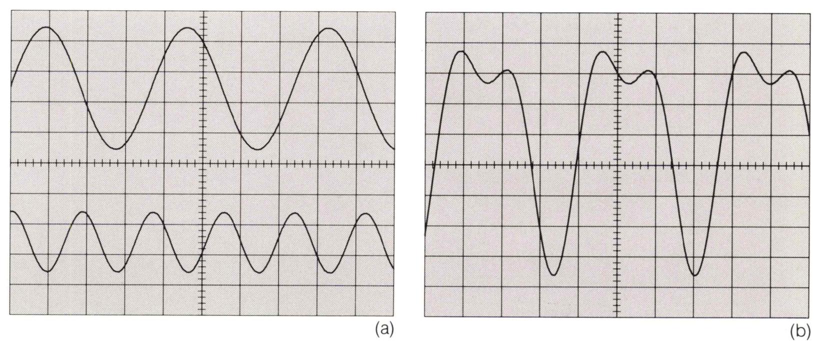


Figure 1.8
Two signals (a) can be combined into one (b) to simulate harmonic distortion at the Channel A output.

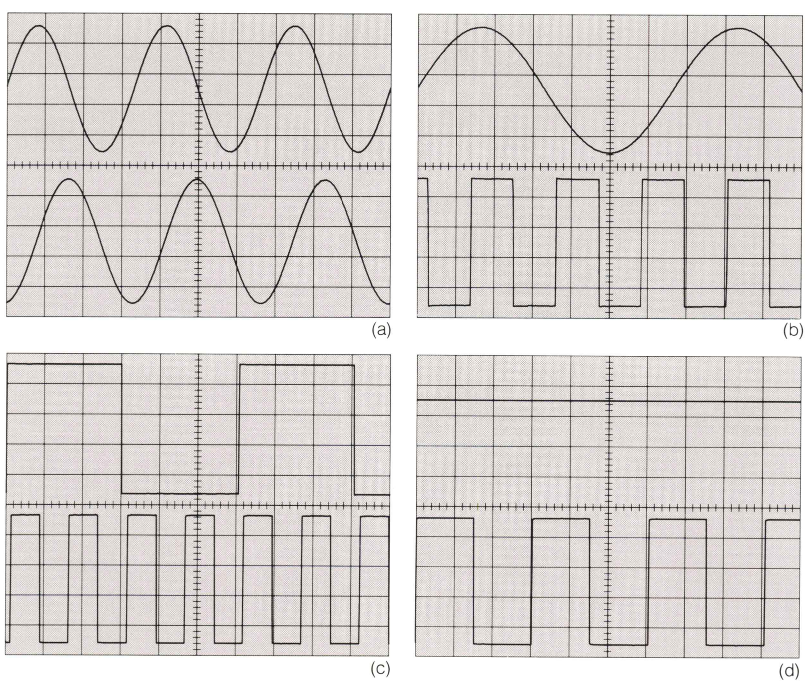


Figure 1.7
Waveform examples at the two outputs: (a) sine-sine, (b) sine-square, (c) square-square, (d) dc-square.

Modulation

The HP 3326A modulation capabilities include both amplitude and phase modulation. These capabilities are summarized in Table 1.1 for each of the four modes. Let's look at each modulation capability in more detail:

• ***Amplitude Modulation***

Internal amplitude modulation is available in the Two-Channel mode on Channel A, while external amplitude modulation capability is provided in all modes and can be applied independently to each channel. With internal modulation, the Channel B signal functions as either a sine wave or square wave modulation source.

Amplitude modulation rates are from dc to 100 kHz. Envelope distortion as low as −46 dB is the result of the linear modulator technique used in the HP 3326A. Internal modulation depth can be set from 0 to 100 percent with 0.1 percent resolution and 5 percent accuracy. Figures 1.9a through 1.9c show examples of amplitude modulaton waveforms.

	Channel A				***Channel B***		***Channel A&B***
	Internal Mod		External Mod		External Mod		External Mod
Mode	AM	PM	AM	PM	AM	PM	Synchronous PM
Two-Channel	Yes	Yes	Yes	Yes	Yes	Yes	No
Two-Tone	No	No	Yes	No	Yes	Yes	Yes
Two-Phase	No	No	Yes	No	Yes	Yes	Yes
Pulse	No	No	Yes	No	Yes	Yes	Yes

Table 1.1 Modulation capabilities in each of the four modes of the HP 3326A.

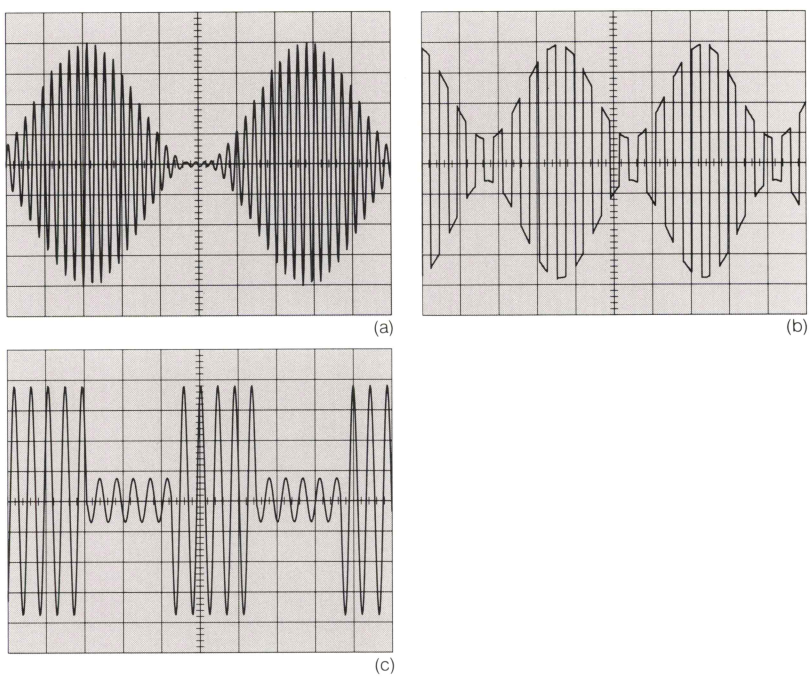


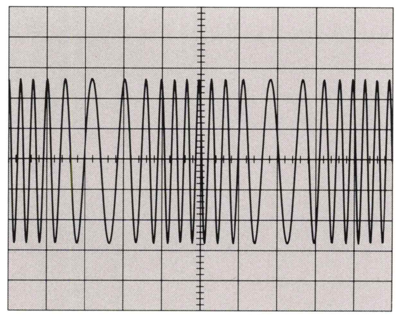
Figure 1.9
Amplitude modulation examples: sinusoidal AM of a (a) sine wave and (b) square wave carrier; (c) square wave AM of a sine wave carrier.

• *Phase Modulation*

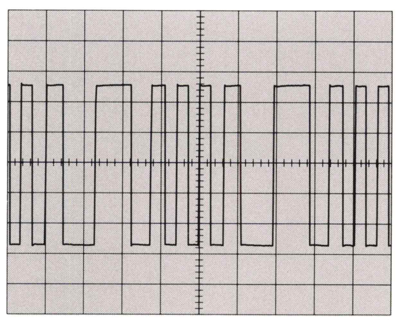
The HP 3326A also features both internal and external phase modulation. Internal phase modulation is available in the Two-Channel mode on Channel A using Channel B as the modulation source. As shown in Table 1.1, external phase modulation capabilities depend upon the mode selected. In the Two-Channel mode, the user can externally phase modulate either or both channels, while in the other modes external PM is possible only with Channel B.

A unique synchronous phase modulation capability is available for both channels in the Two-Tone, Two-Phase and Pulse modes. This capability allows the user to simultaneously phase modulate both channels with a synchronous relationship.

Phase modulation rates can be from dc to 5 kHz with up to ±360 degrees peak deviation and 0.5 percent linearity. Internal accuracy is 5 percent with 1 degree resolution. Figures 1.10a through 1.10c show examples of phase modulation capabilities. The HP 3326A also allows the user to apply simultaneous amplitude and phase modulation at each channel.



(a)



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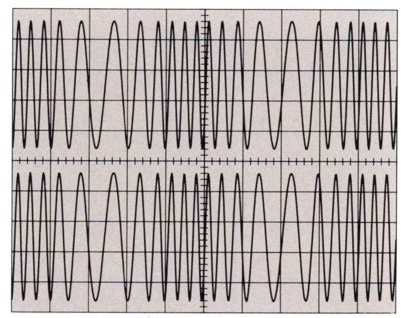


(c)

Figure 1.10
Sinusoidal phase modulation of a (a) sine wave and (b) square wave carrier; (c) synchronous phase modulation of both channels.

Frequency Sweep

The HP 3326A features phase continuous frequency sweep of both channels. The difference in sweep operation between each HP 3326A mode is primarily in the tracking of the Channel B frequency relative to that of Channel A during sweep. The relationship of the Channel B frequency to that of Channel A is summarized in Table 1.2.

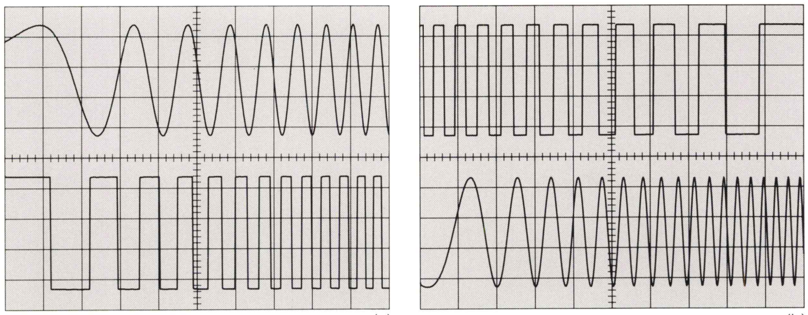
Mode	***Channel B Tracking***
Two-Channel	Channel B frequency is independent of Channel A frequency.
Two-Tone	Channel B frequency is within ±100 kHz of Channel A frequency.
Two-Phase	Channel B frequency is identical to Channel A frequency.
Pulse	Channel B frequency is identical to Channel A frequency.

Table 1.2 The relationship of Channel B frequency to Channel A frequency during sweep.

The HP 3326A allows flexible sweep control with two sweep types—Linear and Discrete. Trigger capability is provided for both continuous and single sweeps with both sweep types. With single sweep, triggering is accomplished from a front panel keystroke, HP-IB command or a rear panel input signal. This trigger can be prearmed with the Sweep Reset function. When armed, the sweep will start within 10 μsec of the trigger signal. Now, let's look at the two frequency sweep types:

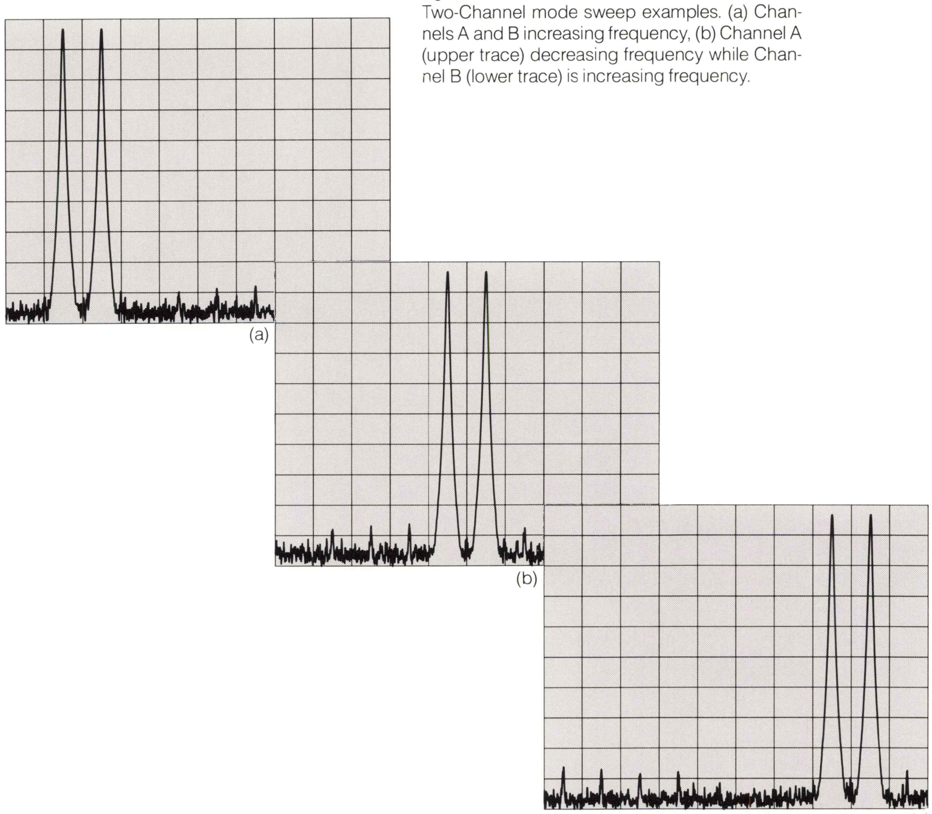
- ***Linear Frequency Sweep***

The sweep direction of either channel may be increasing or decreasing frequency by selecting the appropriate start and stop frequencies (or center frequency and span) in the Linear Ramp mode. A Triangular Sweep mode is also provided for a continuous up-down sweep. Figures 1.11 through 1.15 illustrate some of the linear sweep combinations possible. A rear panel X-drive signal allows the HP 3326A to be used with oscilloscopes and X-Y recorders. During Linear Sweep, a marker can be positioned at a precise point which identifies the corresponding frequencies at each channel. A rear panel Z-blank TTL signal goes high during retrace in the Linear Ramp and Discrete Sweep modes and when sweep is off.



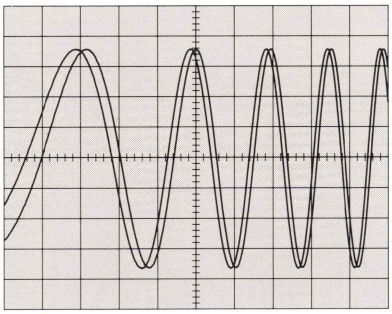
(a) (b)

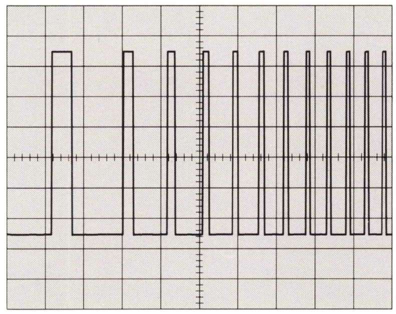
Figure 1.11
Two-Channel mode sweep examples. (a) Channels A and B increasing frequency, (b) Channel A (upper trace) decreasing frequency while Channel B (lower trace) is increasing frequency.



(a) (b) (c)

Figure 1.12
Two-Tone mode sweep example with tone pair at (a) t_1, (b) t_2 and (c) t_3.





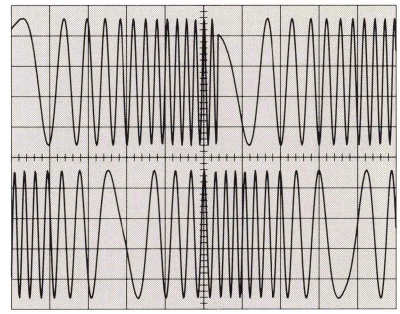


Figure 1.13
Phase difference in the Two-Phase mode is constant during sweep.

Figure 1.14
A swept pulse signal in the HP 3326A Pulse mode. The duty cycle remains constant with frequency.

Figure 1.15
Ramp (upper trace) and Triangular (lower trace) Sweep examples in the Linear Frequency Sweep mode.

• ***Discrete Frequency Sweep***

This capability allows rapid switching from one frequency to another in a user-defined sequence of up to 63 pairs. Discrete Frequency Sweep takes advantage of fast hardware switching and Save-Recall Memory to provide a rapid frequency switching time.

For changes of less than 1 MHz, frequency switching takes place in typically 10 ms and linearly increases to typically 25 ms for changes of 1.0 MHz or greater. This mode is useful in sequential-tone signaling applications such as dual-tone multiple-frequency (DTMF) and pocket pagers. Figure 1.16 illustrates an example of Discrete Frequency Sweep.

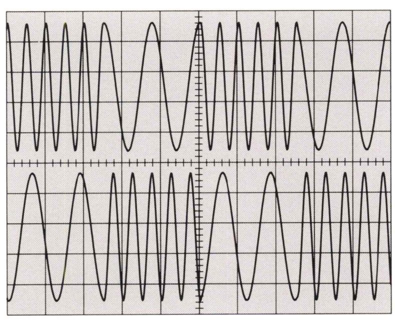


Figure 1.16
Fast frequency transitions occur on both channels in the Discrete Frequency Sweep mode.

2. INSTRUMENT FAMILIARIZATION

INSTRUMENT FAMILIARIZATION

1 Status

Display panel displays frequency (up to 11 digits), amplitude, phase offset, dc offset, sweep frequencies and time, marker frequency, HP-IB address values and error messages. CHAN key selects channel for display and modification. The A and B LEDs indicate channel selected. Channel B phase is indicated by PHASE OFFSET LED. EXT REF LED illuminates when operating with an external frequency reference or High Stability Frequency Option (Option 001).

2 HP-IB Status

LEDs indicate status of HP-IB operation. LOCAL key returns HP 3326A from remote to front panel operation unless local lockout is programmed. LOCAL preceded by blue SHIFT key displays HP-IB address.

3 Sweep

SWEEP keys set start, stop, and either a continuous or single frequency sweep. Ramp sweeps from start to stop frequency while Triangle sweeps from start to stop to start frequencies. Discrete sweep maintains a constant frequency output for a specified dwell time before stepping to the next frequency.

4 Entry

Signal frequency, amplitude, phase, or dc offset is changed by selecting appropriate ENTRY key. PHASE and DC OFFSET keys with blue SHIFT key assign a zero phase value to the signal or removes an entered phase. The blue DUTY CYCLE and % AM/PM DEV entries change the pulse duty cycle, percent AM or PM deviation.

5 Instr State

Setups are saved and recalled from nonvolatile memory registers 0 through 9. Register 0 contains the last setup prior to removing power. Discrete sweep elements are saved and recalled from memory by the SAVE/RECALL keys preceded by blue SHIFT key. Contiguous discrete elements range from 00 to 62 and consist of dwell time and Channel A and B frequencies.

6 Data

Frequency, amplitude, offset, time, memory location, and HP-IB address are entered with the numeric keypad followed by a units suffix.

7 Modify

Frequency, amplitude, offsets and time values are modified with the rotary knob. The arrow keys select display digit modified.

8 Sync A Output

1.2 Vpp square wave output with same frequency as Channel A.

9 Modulation

Internal and external AM and PM sources are selected with the modulation keys. Internal modulation uses Channel B to modulate Channel A. External modulation inputs are on the rear panel.

10 Calibration

MANUAL key initiates an HP 3326A calibration. SELECT key selects the HP 3326A phase calibration source (internal, external or multiphase). External phase calibration inputs are on the rear panel. SELECT preceded by blue SHIFT key initiates self test.

11 Mode

MODE key selects the 2 CHANNEL, 2 PHASE, 2 TONE, or PULSE operating modes. Combined operation sums Channel A and B to produce a composite output at Channel A.

12 Function

Independent function outputs include sine wave, square wave, and dc. The High Voltage Option provides outputs up to 40 Vpp.

Figure 2.1
HP 3326A Front Panel.

1 Modulation Inputs

PM (5 kHz maximum modulation frequency) or AM (100 kHz maximum modulation frequency) is available for either or both channels. AM and PM can operate simultaneously.

2 Calibration Inputs

External calibration sources are connected to the calibration inputs.

3 Channel Outputs

Optional rear panel outputs (Option 003) for Channel A and B.

4 Ext Trig Input

Allows external triggering of single sweeps.

5 Z-Blank/X-Drive Outputs

The Z-BLANK and X-DRIVE OUTPUTS are compatable with most oscilloscopes and plotters. Z-BLANK signal is TTL high during retrace. X-DRIVE provides linear 0 to 10 V ramp proportional to sweep time.

6 HP-IB

Allows remote operation with external controllers.

7 Marker Output

A TTL (0 to 5 V) negative going transition during sweeps.

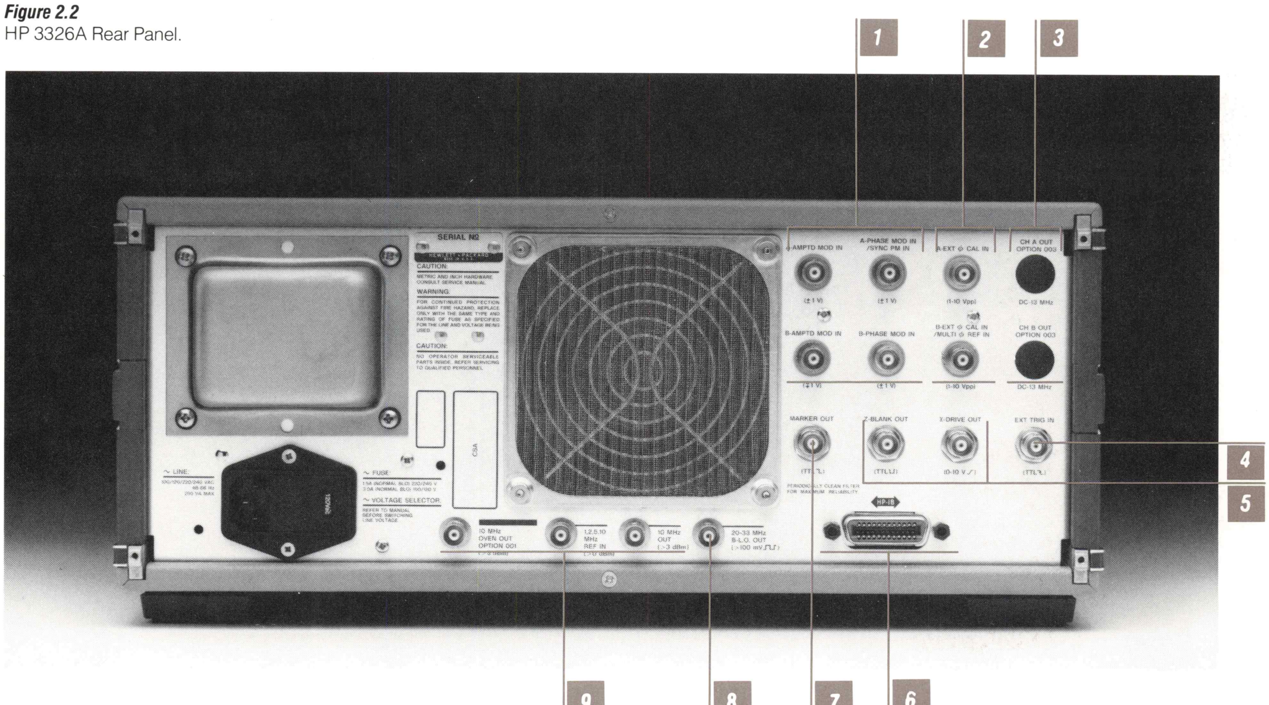
8 20-33 MHz B-L.O. Output

Output offset from Channel B frequency by 20 MHz.

9 Frequency Reference Input/Output

The HP 3326A is phase-locked to stable frequency references with the 1, 2, 5, 10 MHz REF IN connector. Other instruments are phase-locked to the HP 3326A through the 10 MHz OUT connector. The 10 MHz OVEN OUTPUT option (Option 001) provides a high stability frequency reference when connected to 1, 2, 5, 10 MHz REF IN.

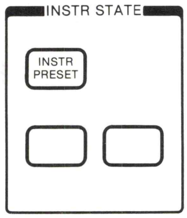
Figure 2.2
HP 3326A Rear Panel.



3. TWO-CHANNEL MODE OPERATION AND APPLICATIONS

TWO-CHANNEL MODE OPERATION
GETTING STARTED

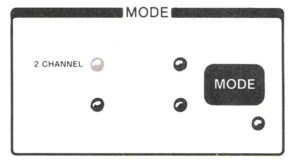
1. Instrument Preset.
To establish a known setup prior to entering setup data, press the green INSTR PRESET key. Upon preset, the HP 3326A assumes the following setup characteristics:



PRESET.

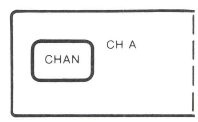
Mode	2 CHANNEL
Frequency A and B	1000 Hz
Amplitude A and B	100 mVp-p
DC offset A and B	0 V
Phase	0 deg
Modulation	Off
Modulation level	30%
Sweep	Off
	Single ramp
	13 MHz span
	1 s sweep
Function A and B	Sine wave
Calibration	Internal
Autocalibration	Off

2. Select Mode—2 CHANNEL.
The preset state places the HP 3326A into the Two-Channel mode as indicated by the illuminated the 2 CHANNEL indicator. In the Two-Channel mode, the HP 3326A operates as two independent sources.



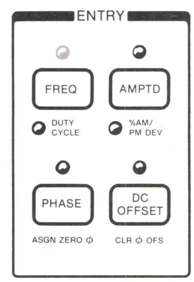
SELECT MODE.

3. Set Entry and Data Parameters.
Prior to entering data parameters, press the CHAN key to select the channel to be modified. The channel selected is indicated by the illuminated channel indicator.



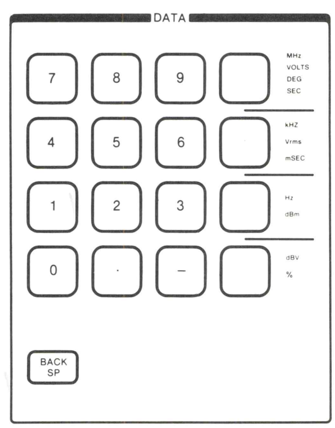
SELECT CHANNEL.

Select an ENTRY key corresponding to the parameter to be modified. An indicator for the FREQ, AMPTD, PHASE, DC OFFSET, DUTY CYCLE and % AM/PM DEV ENTRY keys illuminates after the respective key is selected and the current value for the parameter is displayed.



SET ENTRY.

Enter new values into the display area with the numeric keypad and terminate the entry with the appropriate units key in the DATA block. Prior to ending the entry with the units keys, erroneous entries are corrected by removing display digits with the BACK SPACE key or canceling the entry by pressing an ENTRY key. Entering an invalid value results in an error message and rejection of the entry. Appendix A contains a listing of the error messages and a description of the fault. Figure 3.1 illustrates entering setup values into the HP 3326A.



ENTER VALUES.

1. CHAN (CH A)					
2. AMPTD	1	•	1	2	5 VRMS
3. FREQ	1	0	kHz		

1. CHAN (CH B)					
2. AMPTD	•	3	5	1	VRMS
3. FREQ	3	0	kHz		

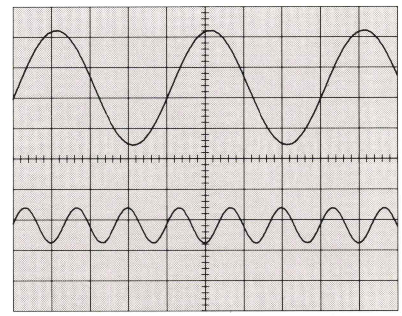
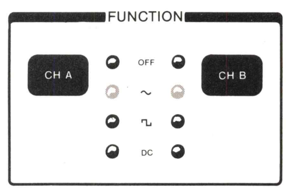


Figure 3.1
Two-Channel mode keystroke example resulting in the above output signals.

4. Select Function.

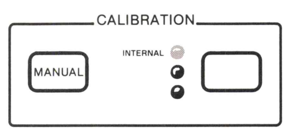
The output waveform for each channel is selected with the FUNCTION keys. The output for each channel can be disabled or set to sine wave, square wave, or dc output (dc offset) only.



SELECT FUNCTION.

5. Connect Device Under Test.

Connect the HP 3326A outputs to the test device and other instruments used in the measurement as required.



CALIBRATE.

6. Calibration.

Before making a measurement, calibrate the HP 3326A with the MANUAL key. Amplitude, dc offset, phase, and internal modulation are calibrated internally when the manual key is pressed.

TWO-CHANNEL MODE APPLICATIONS
SWEPT MIXER MEASUREMENTS

Application
The characterization of mixers usually involves the measurement of frequency response, conversion loss and distortion. Point-to-point cw measurements can be made, but these are slow and tedious. Since the RF and LO input signals and their difference frequency (the IF) must be accurately controlled, two sources are typically required. The use of swept techniques can speed up the measurement and provide characterization over a wide range of frequencies.

Measurement Considerations
The testing of devices such as mixers is somewhat complicated because they operate with different input and output frequencies. Although broadband measurement techniques can be used, the numerous harmonic and spurious signals usually present can limit measurement accuracy. The use of a narrowband tracking network analyzer eliminates these problems by selecting only the desired signal component and provides better accuracy and dynamic range.

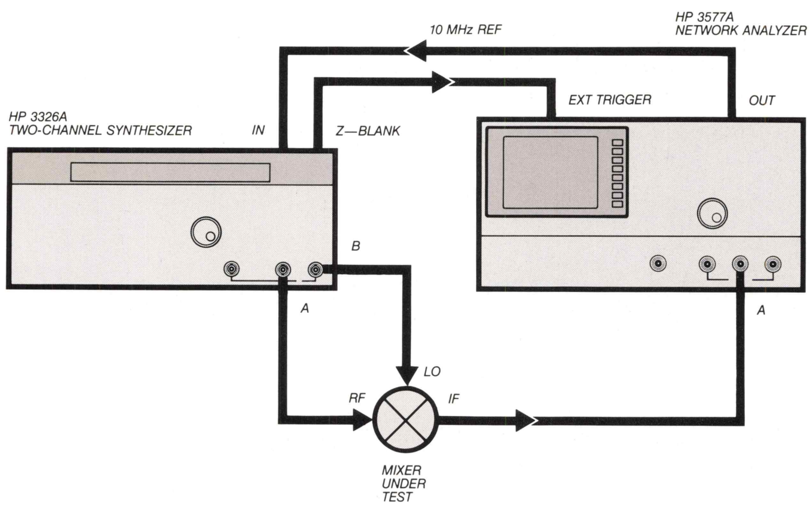
Mixer intermodulation products and group delay are examples of different distortion effects that are important in mixer applications. A mixer intermodulation distortion measurement is illustrated in Chapter 4.

HP 3326A Solution
Figure 3.2 shows a measurement setup using the HP 3326A with an HP 3577A Network Analyzer to make swept measurements of mixer frequency response, conversion loss and group delay. The HP 3326A Channel A output provides the RF input to the mixer. The Channel B output is used to provide a local oscillator signal.

Using the HP 3326A Two-Channel mode, the Channel A sweep is set to the desired mixer input range and the HP 3577A is set to sweep over the corresponding mixer output frequency range. The HP 3326A Z-blank signal externally triggers the HP 3577A in the continuous sweep mode. Both instruments use a common frequency reference and the same sweep time.

To make a measurement, first calibrate by measuring the RF input signal. This is accomplished by replacing the mixer with a through connection, and taking a reference measurement with the HP 3577A set to sweep through the input frequency range. The measurement is initiated with an HP 3326A single sweep keystroke. This reference measurement will be valid at the mixer output if the mixer RF input is linear.

Figure 3.2
Setup for swept mixer testing.



Then use the HP 3577A Normalization function to store the reference measurement. When normalized, the mixer measurement at HP 3577A input A will be displayed as A/D1, where D1 is the reference measurement. With this technique, frequency response flatness can be measured to 0.3 dB, limited by the HP 3577A absolute flatness performance.

Figures 3.3 and 3.4 illustrate frequency response and group delay measurements of a mixer with a 10.7 MHz IF bandpass filter. Mixer flatness and conversion loss is obtained from the frequency response measurement. In this example the HP 3326A Channel A frequency is swept from 2.2 to 3.2 MHz (RF), and the Channel B start and stop sweep frequencies are both set at 8 MHz to produce a cw signal at 8 MHz. The HP 3577A is set to sweep from 10.2 to 11.2 MHz (IF). The HP 3326A was set for sinusoidal output and 0 dBm at both channels.

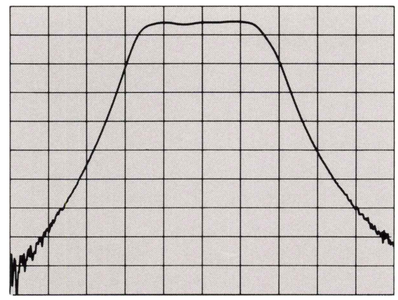


Figure 3.3
Mixer frequency response measurement at IF output. Vertical axis 10 dB/div. Horizontal 10.2 to 11.2 MHz.

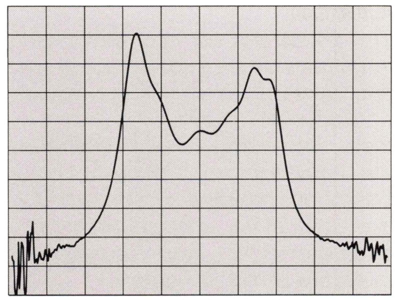


Figure 3.4
Mixer group delay flatness measurement. Vertical axis 20 us/div. Horizontal axis 10.2 to 11.2 MHz.

Application

The phase-locked loop (PLL) is an important circuit in many electronic applications such as communications, consumer electronics, frequency synthesis, and navigation. Although there are many variations in loop design, a basic loop consists of a phase detector, low-pass filter, voltage-controlled oscillator (VCO) and a frequency divider as shown in Figure 3.5.

In a PLL circuit, the phase detector compares the input signal phase with that of the VCO signal after it passes through the frequency divider. The phase detector output is an error signal that is proportional to the difference in phase between its input signals. This error voltage passes through a low-pass filter which supresses noise, high frequency signal components and helps determine loop dynamic performance. The PLL operates in such a way that the VCO and input signals are locked together with a constant phase difference. The measurement of PLL frequency response and transient response are often needed to analyze the performance of these circuits.

Frequency Response Measurement Considerations

The analysis of phase-locked loops has been somewhat difficult for several reasons. First, the controlled variable is frequency, but the error signal is based on phase. Since frequency is the derivative of phase, the phase of the VCO is proportional to the integral of the filtered VCO voltage. This gives the PLL an integrated rather than a linear feedback function.

Second, the phase detector requires two signals to operate and this usually necessitates that analysis be done with the loop closed. Third, many of the PLL components such as the phase detector or the VCO are often non-linear so that input signals with varying peak phase deviations can cause varying loop responses.

Several techniques have been developed to analyze PLL circuits. One technique is to frequency modulate the input signal and monitor the resulting VCO control voltage. This technique works well when the PLL is used as a frequency demodulator, but for other applications it is necessary to assume that the VCO has constant gain independent of the modulation rate or signal amplitude. Since the FM modulation index is dependent upon the rate, large phase deviations can be produced which cause the loop to operate in non-linear regions.

Another technique is to insert a signal into the loop and analyze the resulting response, but the process of injecting a signal can alter loop performance. The individual elements of the loop can be analyzed separately, but loop interactions are usually difficult to predict. Analysis of individual loop elements is most valuable in diagnosing faulty loop operation.

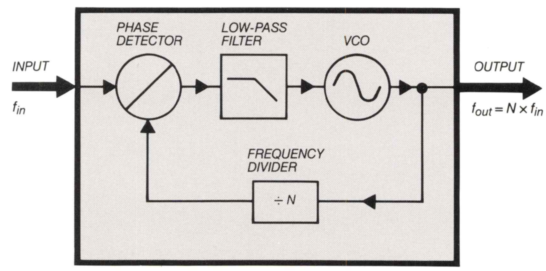


Figure 3.5
Basic phase-locked loop block diagram.

HP 3326A Solution

A phase modulation technique can be used that offers unique capabilities which enhance the user's ability to analyze PLL circuits and that overcomes many of the disadvantages of other methods. The HP 3326A is well suited to this technique and its Two-Channel capability can simplify PLL measurements by reducing equipment complexity.

The frequency stability of the HP 3326A makes it ideal for narrowband loop testing. The calibrated and wide range output level of the HP 3326A is useful when testing a PLL circuit with a response that is dependent upon input signal level. Wide range level control is also important for generating a low PM index for frequency response measurements on PLL circuits with one of the three methods available.

The HP 3326A can be used to make a variety of PLL frequency response measurements as summarized in Table 3.1. The test setup and details of each method are considered separately.

Method	Test Rates	Equipment Required	Comments
1	20 Hz to 5 kHz	1ea HP 3326A Two-Channel Synthesizer 1ea Spectrum Analyzer (HP 3585A) 1ea Oscilloscope (HP 1740A) 1ea Phase Detector	For swept measurement of magnitude response of PLL circuits with inputs and outputs up to 13 MHz. HP 10534A Mixer is used as a Phase Detector with RF and LO input frequencies down to 50 kHz.
2	5 Hz to 5 kHz	1ea HP 3326A Two-Channel Synthesizer 1ea Network Analyzer (HP 3577A) 1ea Oscilloscope (HP 1740A) 1ea Phase Detector 1ea 50 Ohm Power Splitter (HP 11652-60009)	For swept measurement of magnitude and phase response of PLL circuits with inputs and outputs up to 13 MHz. HP 10534A Mixer is used as a Phase Detector with RF and LO input frequencies down to 50 kHz.
3	Resolution of spectrum analyzer to 13MHz.	1ea HP 3326A Two-Channel Synthesizer 1ea RF Spectrum Analyzer (HP 3585A, HP 8568)	For swept measurement of magnitude response of PLL circuits with inputs up to 13 MHz and outputs up to the limit of the spectrum analyzer.

Table 3.1 A comparison of three methods using the HP 3326A to measure the frequency response of phase-locked loops.

• *Method 1*

A swept display of PLL magnitude vs phase can be obtained using the setup shown in Figure 3.6. This method yields a fast display response and is valuable in making loop adjustments. Using this setup, loops with input and output frequencies up to 13 MHz can be analyzed. Phase modulation rates up to the 5 kHz limit of the HP 3326A phase modulator are possible. The lower limit on the rate is determined by the minimum frequency of the spectrum analyzer/tracking generator.

The frequency response of the HP 3326A phase modulator is relatively flat at low modulation rates, but rolls off for rates near the modulation bandwidth. The frequency response curve shown in Figure 3.7 shows a typical HP 3326A phase modulator frequency response.

The effects of the HP 3326A phase modulator frequency response can be accounted for by taking a reference reading with the phase-locked loop out of the circuit and replacing it with a through connection. In many PLL circuits, the input and output frequencies are different and the HP 3326A Channel A frequency will have to be temporarily changed to obtain a reference reading. The reference reading can be stored in the spectrum analyzers trace memory and subtracted out from the measurement with the loop in the circuit.

Proper phase demodulation occurs when the inputs of phase detector number 2 are at the same frequency and have a phase relationship that centers the detector in its linear range as observed on the oscilloscope. With the HP 3326A in the Two-Channel mode, the Channel B phase is adjusted for linear operation.

The amount of phase deviation is adjusted to assure that both the PLL and the phase demodulator are operating in their linear regions. Some PLL circuits have significant peaking and it may be necessary to reduce the deviation so that gain compression does not occur. Some PLL circuits are sensitive to input signal level variations and should be tested at various input levels.

With this method the spectrum analyzer tracking generator output is used to phase modulate HP 3326A Channel A. The modulated RF output from HP 3326A Channel A is used as the input signal to the PLL under test. This produces a phase error which the loop responds to by phase modulating the VCO. The modulated VCO signal is then demodulated by phase detector number 2 and the frequency response is displayed on the spectrum analyzer. An example of a typical PLL frequency response measurement is shown in Figure 3.8.

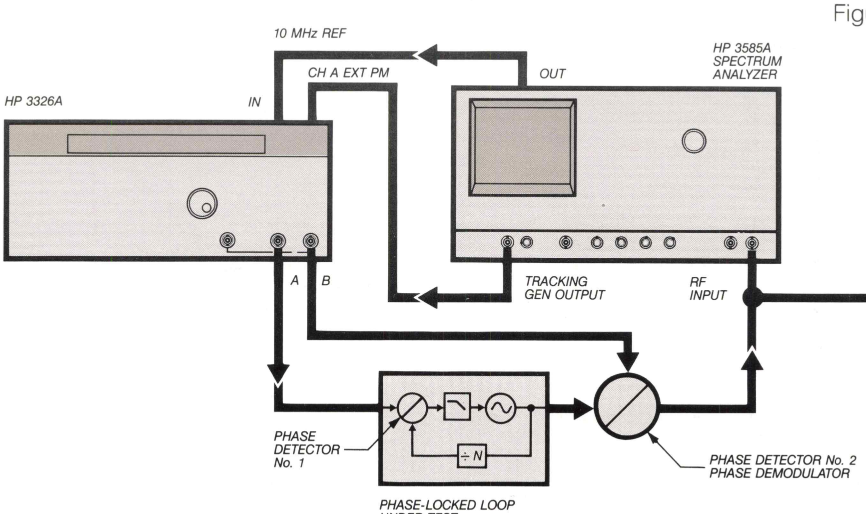


Figure 3.6
Setup for frequency response measurement using Method 1.

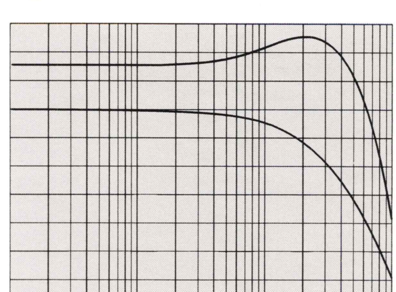


Figure 3.7
Magnitude and phase response of HP 3326A phase modulator. Vertical axis: upper trace 2 dB/div.; lower trace 45 deg/div. Horizontal axis 10 Hz to 15 kHz.

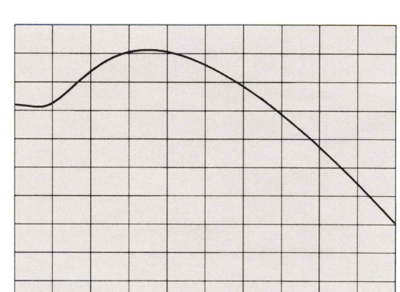


Figure 3.8
Frequency response of a typical phase-locked loop using Method 1. Vertical axis 2 dB/div.; horizontal axis 250 Hz to 5 kHz.

• Method 2

With the use of a network analyzer instead of a spectrum analyzer, swept frequency response measurements can be made that yield phase as well as magnitude information. The test setup and measurement procedure for this method are very similar to that of method 1 and is shown in Figure 3.9. The only exception is that for certain phase detectors such as mixers, it is possible to operate on either a positive or negative slope which results in a 180 degree phase shift.

With the HP 3577A Network Analyzer, frequency response measurements can be made on loops with PM rates as low as 5 Hz. As in method 1, the upper PM rate is limited to 5 kHz by the frequency response of the HP 3326A phase modulator. Effects of this frequency response, particularly below 5 kHz, can be removed by taking a reference measurement as in Method 1. The HP 3577A built-in normalization capability is convenient for automatically removing this effect. Figure 3.10 is an example of a typical PLL magnitude and phase response using this method.

• Method 3

This method is useful for obtaining the magnitude frequency response of PLL circuits with wide bandwidths and is not restricted to loops with output frequencies within the range of the HP 3326A. The loop input frequency however must be within the HP 3326A's range. Measurements can be made with PM rates limited on the low end by the resolution of the spectrum analyzer used and on the high end by the difference of the HP 3326A Channel A and Channel B frequencies.

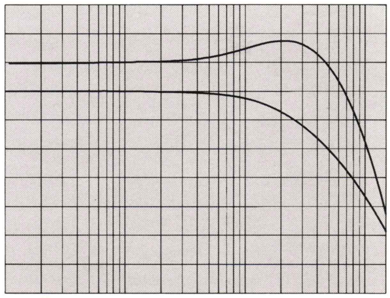


Figure 3.10
Magnitude and phase response of a typical phase locked loop using Method 2, Vertical axes: upper trace 1 dB/div.; lower trace 30 deg/div. Horizontal axis 5 Hz to 5 kHz.

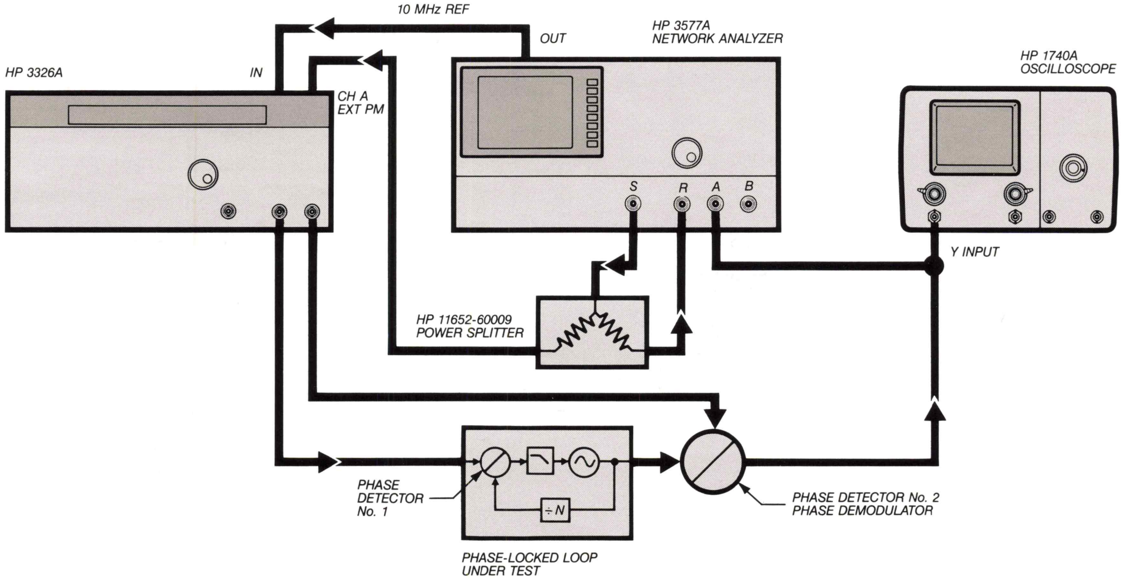


Figure 3.9
Setup for frequency response measurement using Method 2.

The test setup for this method is shown in Figure 3.11. This method is useful because it requires few instruments and the test setup is simple. The HP 3326A is set to the Two-Channel mode and the output combiner is used to provide a composite PLL input signal consisting of two frequencies. This is equivalent to a signal with both AM and PM components. If the phase detector in the PLL is operated near quadrature, the AM component will be removed and only the PM component remains. The PM rate is determined by the frequency difference between the HP 3326A Channel A and B frequencies.

The PM index is set by the ratio between the HP 3326A Channel A and B signal levels and is approximately (level B/level A)/2 where level A is larger. This index is normally set to less than 0.1 radian so that the phase deviation produced is mainly from the first sideband and the PLL operates is a linear region. The first sideband level, as observed on the spectrum analyzer closely tracks the PLL closed loop frequency response.

To make a measurement, the setup of Figure 3.11 is used. The spectrum analyzer is set so that it sweeps from the carrier frequency out to the PLL bandwidth of interest. With the HP 3326A Channel A frequency set to the PLL input frequency, adjust the Channel B frequency offset (positive direction) to produce a first PM sideband at the desired frequency corresponding to a test frequency within the loop bandwidth. This Channel B offset is then varied for each sweep of the spectrum analyzer.

The HP 3585A and HP 8568A Spectrum Analyzers have a Max Hold function which is useful for storing the first sideband levels at each of the different offsets for each sweep. It is important to set the resolution bandwidth of the spectrum analyzer to resolve the spacing between the carrier and the sidebands. An example of a PLL frequency response is shown in Figure 3.12. The large signal at the start frequency is the carrier. The amplitude of each of the sidebands traces out the PLL frequency response.

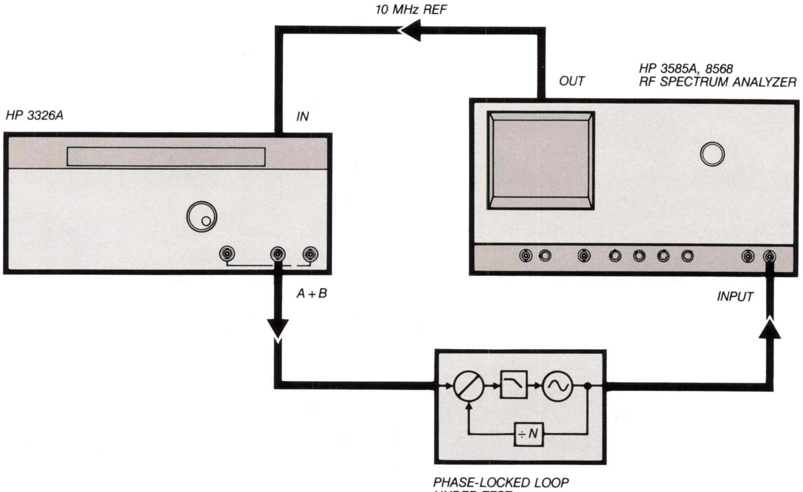


Figure 3.11
Setup for measuring frequency response with Method 3.

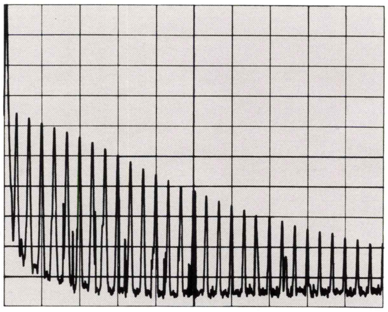


Figure 3.12
Typical phase-locked loop frequency response measurement using Method 3. The first signal is the 350 kHz carrier. Vertical axis 10 dB/div.; Horizontal axis 350 kHz to 365 kHz.

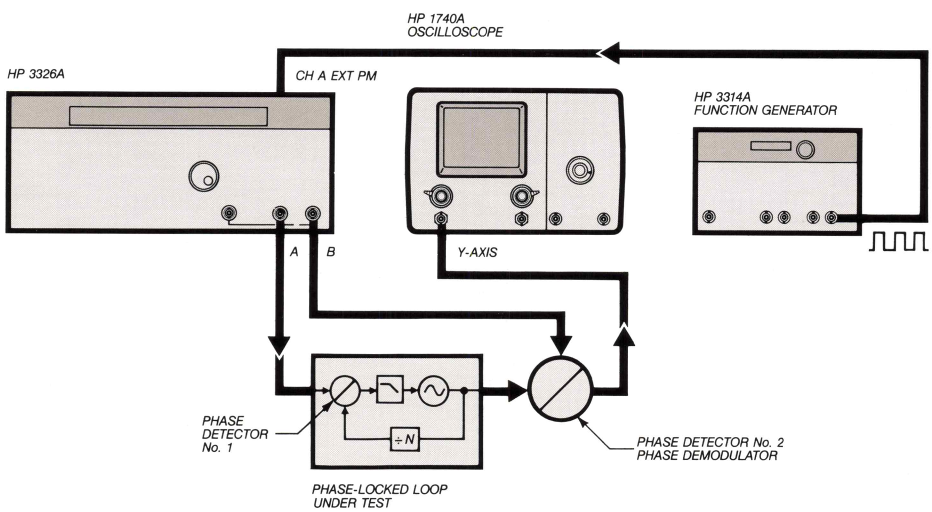
Transient Response Measurement Considerations

The time domain response of a PLL circuit to a step change in input phase is useful for determining loop parameters such as rise time, overshoot and damping factor. These parameters imply many of the same PLL characteristics that can be measured with frequency response techniques, however they are most useful in determining loop settling time and dynamic response performance.

HP 3326A Solution

Figure 3.13 shows a test setup for measuring PLL transient response. In this setup the HP 3326A Channel A output phase is switched between two values using external square wave PM. The HP 3314A Function Generator is used to produce a square wave signal. The rise and fall time of the HP 3326A phase modulator is approximately 6 μsec and useful measurements can be made on loops with bandwidths of approximately 1 kHz or less.

The phase modulated Channel A signal is applied to the PLL input and the output from the VCO is demodulated by a phase detector. The loop time domain response to the phase change is displayed on the oscilloscope. A typical response is shown in Figure 3.14. Linear operation of both phase detectors should be maintained the same as for frequency response testing.



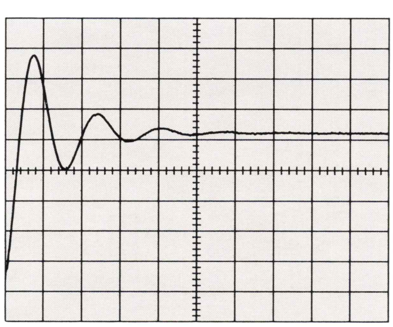


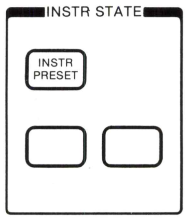
Figure 3.13
Setup for measuring transient response.

Figure 3.14
Typical phase-locked loop transient response measurement. Vertical axis 50 mV/div.; Horizontal axis 1 ms/div.

4. TWO-TONE MODE OPERATION AND APPLICATIONS

TWO-TONE MODE OPERATION
GETTING STARTED

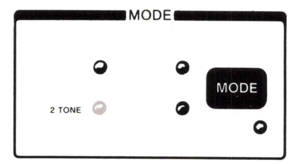
1. Instrument Preset.
To establish a known setup prior to entering setup data, press the green INSTR PRESET key. Upon preset, the HP 3326A assumes the following setup characteristics:



PRESET.

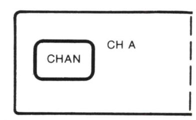
Mode	2 CHANNEL
Frequency A and B	1000 Hz
Amplitude A and B	100 mVp-p
DC offset A and B	0 V
Phase	0 deg
Modulation	Off
Modulation level	30%
Sweep	Off
	Single ramp
	13 MHz span
	1 s sweep
Function A and B	Sine wave
Calibration	Internal
Autocalibration	Off

2. Select Mode—2 TONE.
For Two-Tone setups, press the MODE key to illuminate the 2 TONE indicator. The HP 3326A now operates as two tracking sources with the Channel B frequency capable of being offset from Channel A by 100 kHz.



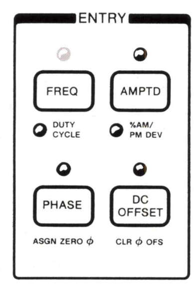
SELECT MODE.

3. Set Entry and Data Parameters.
Prior to entering data parameters, press the CHAN key to select the channel to be modified. The channel selected is indicated by the illuminated channel indicator.



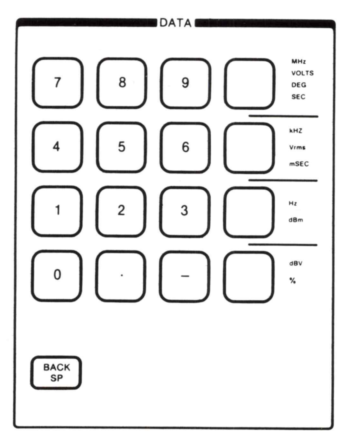
SELECT CHANNEL.

Select an ENTRY key corresponding to the parameter to be modified. An indicator for the FREQ, AMPTD, PHASE, DC OFFSET, DUTY CYCLE and % AM/PM DEV ENTRY keys illuminates after the respective key is selected and the current value for the parameter is displayed.



SET ENTRY.

Enter new values into the display area with the numeric keypad and terminate the entry with the appropriate units key in the DATA block. Prior to ending the entry with the units keys, erroneous entries are corrected by removing display digits with the BACK SPACE key or canceling the entry by pressing an ENTRY key. Entering an invalid value results in an error message and rejection of the entry. Appendix A contains a listing of the error messages and a description of the fault. Figure 4.1 illustrates entering setup values into the HP 3326A.



ENTER VALUES.

1. CHAN (CH A)						
2. AMPTD	1	•	1	2	5	VRMS
3. FREQ	8	•	0	0	5	kHz

1. CHAN (CH B)						
2. AMPTD	1	•	1	2	5	VRMS
3. FREQ	1	0	•	0	5	kHz

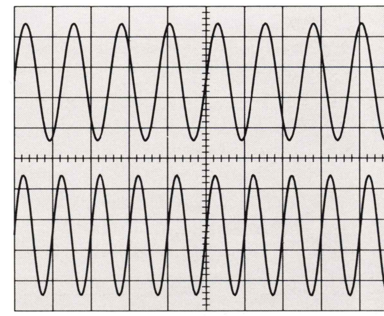
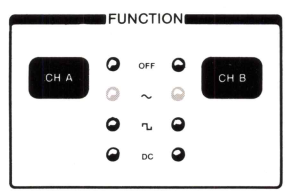


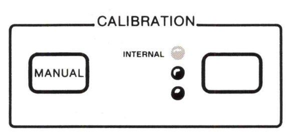
Figure 4.1
Two-Tone mode keystroke example resulting in the above output signals.

4. Select Function.
The output waveform for each channel is selected with the FUNCTION keys. The output for each channel can be disabled or set to sine wave, square wave, or dc output (dc offset) only.



SELECT FUNCTION.

5. Connect Device Under Test.
Connect the HP 3326A outputs to the test device and other instruments used in the measurement as required.



CALIBRATE.

6. Calibration.
Before making a measurement, calibrate the HP 3326A with the MANUAL key. Amplitude, dc offset, phase, and internal modulation are calibrated internally when the MANUAL key is pressed.

TWO-TONE MODE APPLICATIONS SWEPT TWO-TONE INTERMODULATION DISTORTION

Application

Measurement of intermodulation (IMD) products can yield important information about the non-linear characteristics of a circuit or system. These characteristics relate to second and third-order distortion properties of many devices such as voice grade and consumer audio amplifiers, mixers, and crystal filters. Applications can be found in many areas of communications including single sideband, AM and FM transceivers, modems and voiceband data transmission used in telecommunications and high frequency radio teletype.

Measurement Considerations

The intermodulation method of measuring distortion uses a combined driving signal normally composed of two sine wave signals at different frequencies. A variation of this method, known as transient intermodulation distortion (TIM), uses a combination of sine wave and square wave signals and is useful in applications where dynamic distortion performance is important.

The IMD method is useful because second and third-order distortion measurements are not affected by the harmonic distortion of the signal source. Such harmonic distortion does not occur at the same frequencies as the intermodulation distortion produced by the device under test. Thus a spectrum analyzer can be used to select just the distortion products produced by the device under test.

A common method uses a combination of two relatively high frequency signals of equal amplitude as the driving signal. For audio frequency measurements, their frequencies are typically separated by a few hundred Hertz. The separation is typically 10 kHz to 100 kHz for RF measurements. Figure 4.2 illustrates the distortion products using this method.

The distortion sidebands at frequency f_b-f_a are second-order products and are much lower in frequency than the input signals f_a and f_b. The second-order distortion is equal to the ratio of the amplitude of the signal at frequency f_a-f_b to that of the sum of the signals at f_a and f_b.

The third-order distortion products are gathered around the frequencies of the two driving signals at $2f_a$-f_b and $2f_b$-f_a. Third-order distortion is equal to the ratio of the sum of the amplitudes of these third-order products to the sum of the amplitudes of the driving signals at f_a and f_b.

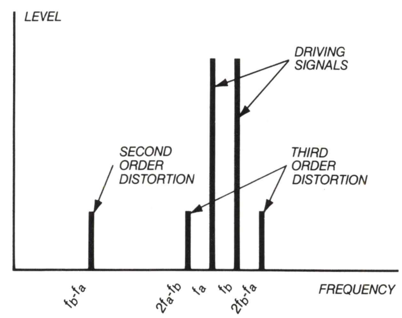


Figure 4.2
Third-order intermodulation distortion products.

HP 3326A Solution

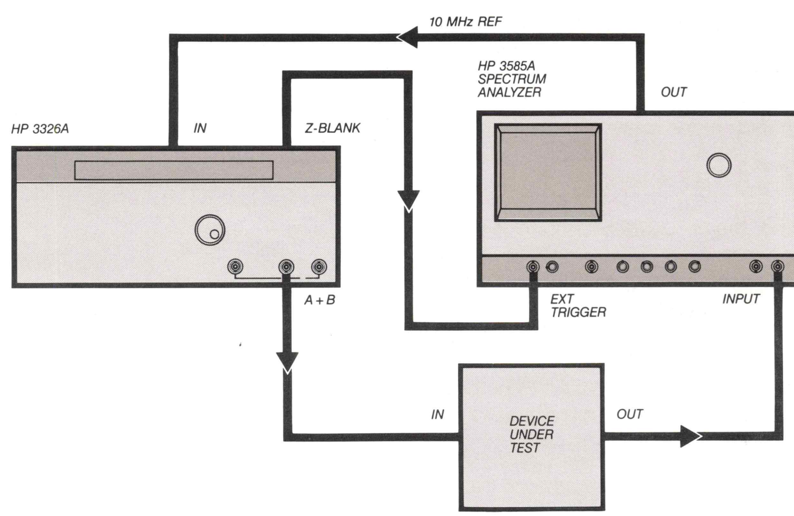
The HP 3326A can be used with an HP 3585A Spectrum Analyzer as shown in Figure 4.3 to make swept IMD measurements. Using the Two-Tone mode and the internal combiner the HP 3326A can produce a Two-Tone signal at the Channel A output with a third-order IMD level of −80 dBc (below +13 dBm and 1 MHz).

This built-in capability eliminates the need for two separate sources and an external combiner. Combinations of sine wave and square wave signals can be produced for both conventional and transient IMD testing. Independent levels can be set for each tone to establish the proper level ratio.

This HP 3326A/3585A system provides swept IMD measurements resulting in characterization of IMD performance over the frequency range of interest. The HP 3326A Z-blank signal is used to trigger the HP 3585A sweep. With a common frequency reference and identical sweep times for both the HP 3326A and HP 3585A, the display on the HP 3585A Spectrum Analyzer can be set to track the desired IMD product or the frequency response of the device under test.

The HP 3585A resolution bandwidth should be set wide enough to allow for small tracking offsets during the HP 3326A sweep and narrow enough to resolve the distortion product of interest.* During a measurement it is important that the HP 3326A and the HP 3585A automatic calibration functions be disabled to prevent possible loss of tracking during periodic calibration.

Figure 4.3
Setup for swept intermodulation distortion measurements using the HP 3326A.



*To assure proper frequency tracking it may be necessary to disable HP 3585A multi-loop operation. This may be accomplished through the use of HP 3585A Test Mode 06 (See HP 3585A Service Manual pg. 11-3).

Using this setup, a reference trace is first taken of the frequency response of the device under test using only the Channel A output from the HP 3326A. This is accomplished by disabling the internal combiner and setting the Channel A start/stop sweep frequencies to sweep the IMD response frequency range. The same start/stop frequencies are set on the HP 3585A. With the device under test connected, a single sweep is triggered on the HP 3326A, and the reference frequency response is displayed on the HP 3585A display. This reference frequency response is stored in the the HP 3585A trace memory using the Store A→B function.

Next, the HP 3326A Channel A and B sweep frequencies are set to produce a two-tone signal that will result in the desired IMD products over the frequency range of the reference sweep. The HP 3326A internal combiner is turned on and the combined output is at the Channel A output connector.

The HP 3326A single sweep function is triggered and the response on the HP 3585A display is stored in trace memory A. The intermodulation distortion level is the difference between the displayed IMD response and the reference reading in trace memory B which can be seen by viewing both trace A and B simultaneously.

• *IF Amplifier Example*

An example of swept third-order IMD measurement of an IF amplifier and filter is shown in Figure 4.4. The swept two-tone frequencies from HP 3326A Channel A is from 430 kHz to 480 kHz and Channel B is swept from 431 kHz to 481 kHz. The HP 3326A internal combiner is turned on for a combined output. Equal amplitude signals of −30 dBm are used at both channels and sweep time is 20 seconds. The HP 3585A Spectrum Analyzer is set to sweep from 429 kHz to 479 kHz with a resolution bandwidth of 100 Hz. A reference frequency response measurement is made with the HP 3326A set to sweep from 429 kHz to 479 kHz. In this example, the third-order IMD level can be seen as the difference between the upper reference trace and the lower measurement trace of Figure 4.4.

• *Mixer Example*

To measure the third-order IMD response of a mixer, the HP 3326A is set to produce two closely spaced signals f_a and f_b with the internal combiner turned on. This two-tone signal is used as the RF input to the mixer and is mixed with a local oscillator to produce two IF signals with third-order distortion products as shown in Figure 4.5.

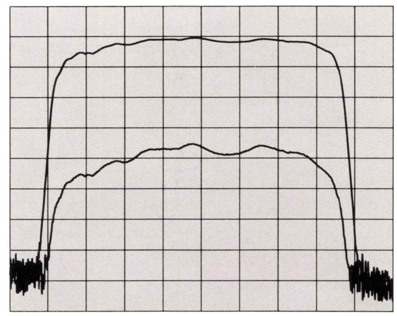
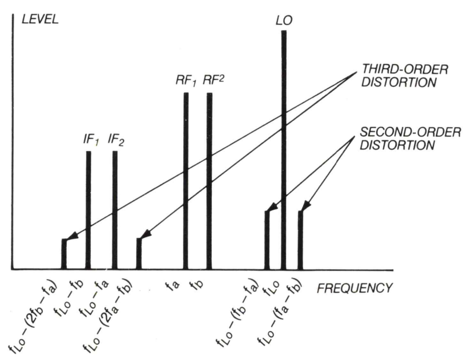


Figure 4.4
Swept third-order distortion measurement of an IF amplifier and filter. Distortion level is the difference between the reference trace (upper) and the measurement trace (lower) . Vertical axis 10 dB/div.; Horizontal axis 429 kHz to 479 kHz.

Figure 4.5
Mixer distortion products.



An example of a swept third-order mixer distortion measurement is shown in Figure 4.6. In this example, the HP 3326A Channel A frequency is swept from 10.3 to 9.7 MHz while Channel B frequency is swept from 10.31 to 9.71 MHz. With a mixer local oscillator frequency of 10.475 MHz, the HP 3585A Spectrum Analyzer is set to sweep from 155 kHz to 755 kHz to track one of the third-order responses during the measurement. As in the previous example, a reference frequency response measurement should be taken. The HP 3326A Channel A sweep should be from 10.32 MHz to 9.72 MHz during the reference sweep.

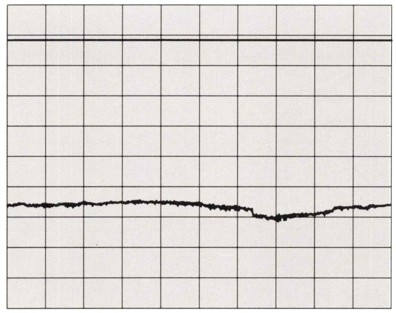


Figure 4.6
Swept third-order distortion of a mixer at the IF output. Distortion level is the difference between the two traces. Vertical axis 10 dB/div.; Horizontal axis 155 kHz to 755 kHz.

Application

Selective calling systems are used in communications for enabling of predetermined communication equipment. An example of this is dual-tone multiple-frequency (DTMF) signaling used in touch-tone telephone equipment. Multiple-tone signalling is also used in personal pagers and mobile radio applications. These applications require one or more sources with fast frequency switching to simulate tone encoders and test tone decoders.

Measurement Considerations

Available selective calling systems represent a wide variety of tone formats. These formats differ in the number of tones present simultaneously, the time duration and amplitude of each tone, and the number of tones in a sequence. In communication systems with a large number of receiving devices, the tone format can be complex in order to accomodate many different device addresses. Let's look at an example with the DTMF format:

- ***Dual-Tone Multiple-Frequency (DTMF)***

This format requires a sequence of tone pairs as specified in tone encoding standards such as EIA RS-470, Bell Technical Reference Pub. 48005 and CCITT. Table 4.1 lists the tone-pair frequencies for each touch-tone digit.

The critical level, timing, frequency accuracy and distortion performance parameters are listed in Table 4.2. A typical DTMF timing sequence is shown in Figure 4.7.

	High-Group Frequencies(Hz)			
Low-Group Frequencies (Hz)	1209	1336	1477	1633
697	1	2	3	A
770	4	5	6	B
852	7	8	9	C
941	*	0	#	D

Table 4.1 DTMF Frequency Assignments.

Parameter	**Performance Standard**
Minimum Tone Duration	50 ms
Minimum Interdigital Time	45 ms
Minimum Cycle Time	100 ms (10 tones per second)
Nominal Signal Level	−6 to −4 dBm (600 Ohms)
Frequency Accuracy	± 1.2%
Total Distortion	≤10% above 500 Hz (Bell) ≤2% below 3400 Hz (CCITT)

Table 4.2 DTMF Performance Parameters.

HP 3326A Solution

The HP 3326A Discrete Sweep function can be used to generate rapid tone sequences at either or both of its two outputs. This feature takes advantage of fast internal hardware switching time (as fast as 5 ms) and internal Save-Recall Memory for a frequency list.

The frequencies of each channel and a corresponding dwell time are stored for each element of Discrete Sweep. Up to 63 frequency-time combinations can be stored in memory and then sequentially accessed using single or continuous sweep triggering. In the single sweep mode, an external signal can be used to trigger the sweep. Individual tones may be accessed through the Recall Discrete function. The amplitude of the tones are all equal during Discrete Sweep.

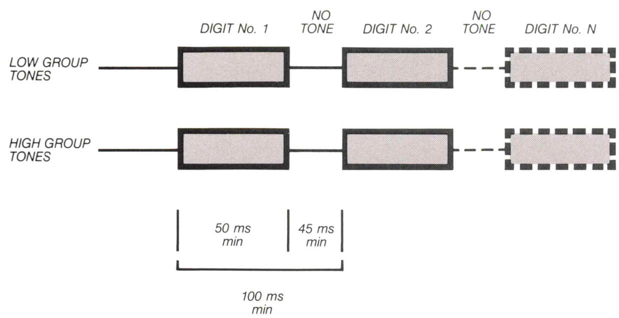


Figure 4.7
The timing sequence for a dual-tone multiple-frequency (DTMF) signal.

• *DTMF Example*

The following procedure shows the keystroke sequence for setting up a DTMF signal corresponding to the digits 7-1-5.

1. Select the Two-Channel mode and set the amplitude to 0.38 Vrms. This level is approximately equal to the voltage into 600 Ohms at −6 dBm. Activate the output combiner and clear the discrete memory before proceeding.

2. Set Channel A frequency to 852 Hz and Channel B frequency to 1209 Hz. This corresponds to the DTMF 7 digit. Set sweep dwell time to 50 ms and store this frequency pair and dwell time in discrete memory location 00.

3. Set Channel A and Channel B frequencies to 0 Hz (or alternately to a frequency above the cutoff frequency of a low-pass filter optionally placed in the HP 3326A output). Set sweep dwell time to 45 ms and store in location 01. This corresponds to an interdigital no-tone state.

4. Set the Channel A and B frequencies to 697 Hz and 1209 Hz (DTMF 1) respectively, with the same dwell time and store in location 01. Repeat for the frequency pair 770 Hz and 1336 Hz (DTMF 5) and same dwell time and store in location 02.

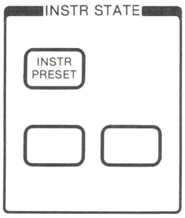
5. Repeat Step 3 for the interdigital no-tone state using location 03.

6. Select the Discrete Sweep mode, then trigger the sweep sequence with a single or continuous sweep keystroke. The combined DTMF signal is available at the Channel A output with the HP 3326A combiner activated.

5. TWO-PHASE MODE OPERATION AND APPLICATIONS

TWO-PHASE MODE OPERATION
GETTING STARTED

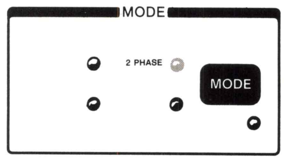
1. Instrument Preset.
To establish a known setup prior to entering setup data, press the green INSTR PRESET key. Upon preset, the HP 3326A assumes the following setup characteristics:



PRESET.

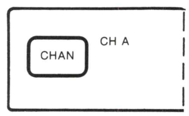
Mode	2 CHANNEL
Frequency A and B	1000 Hz
Amplitude A and B	100 mVp-p
DC offset A and B	0 V
Phase	0 deg
Modulation	Off
Modulation level	30%
Sweep	Off
	Single ramp
	13 MHz span
	1 s sweep
Function A and B	Sine wave
Calibration	Internal
Autocalibration	Off

2. Select Mode—2 PHASE.
For Two-Phase setups, press the MODE key to illuminate the 2 PHASE indicator. The HP 3326A now operates as two tracking sources with a variable phase offset.



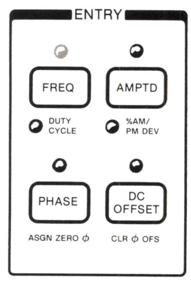
SELECT MODE.

3. Set Data and Entry Parameters.
Prior to entering data parameters, press the CHAN key to select the channel to be modified. The channel selected is indicated by the illuminated channel indicator.



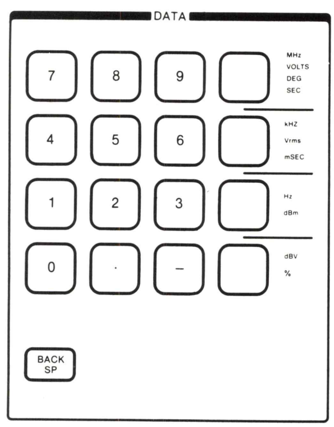
SELECT CHANNEL.

Select an ENTRY key corresponding to the parameter to be modified. An indicator for the FREQ, AMPTD, PHASE, DC OFFSET, DUTY CYCLE and % AM/PM DEV ENTRY keys illuminates after the respective key is selected and the current value for the parameter is displayed.



SET ENTRY.

Enter new values into the display area with the numeric keypad and terminate the entry with the appropriate units key in the DATA block. Prior to ending the entry with the units keys, erroneous entries are corrected by removing display digits with the BACK SPACE key or canceling the entry by pressing an ENTRY key. Entering an invalid value results in an error message and rejection of the entry. Appendix A contains a listing of the error messages and a description of the fault. Figure 5.1 illustrates entering setup values into the HP 3326A.



ENTER VALUES.

1. CHAN (CH A)						
2. AMPTD	1	•	1	2	5	VRMS
3. FREQ	1	0	kHz			

1. CHAN (CH B)						
2. AMPTD	1	•	1	2	5	VRMS
3. PHASE	4	5	DEG			

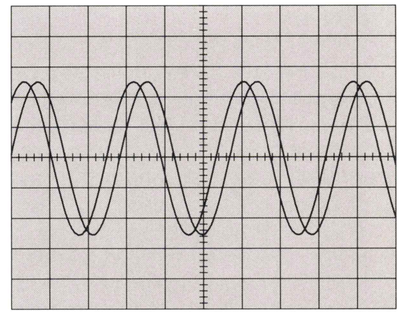


Figure 5.1
Two-Phase mode keystroke example resulting in the above output signals.

4. Select Function.

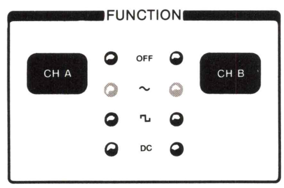
The output waveform for each channel is selected with the FUNCTION keys. The output for each channel can be disabled or set to sine wave, square wave, or dc output (dc offset) only.

5. Connect Device Under Test.

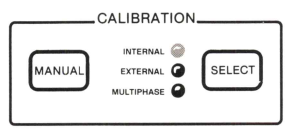
Connect the HP 3326A outputs to the test device and other instruments used in the measurement as required. For two-phase measurements, the Channel A output is used as the output reference.

6. Calibration.

Before making a measurement, calibrate the HP 3326A with the MANUAL key. Amplitude, dc offset, and internal modulation are calibrated internally when the MANUAL key is pressed. Phase calibrations are based upon the selection made with the CALIBRATION SELECT key. Internal calibration senses phase at the HP 3326A outputs. External calibration senses phase at a point external to the HP 3326A through the CH A EXT CAL INPUT and CH B EXT CAL INPUT as shown in Figure 5.2. Multiphase calibration uses the phase of an external frequency source as a reference and calibrates the HP 3326A phase with respect to that reference. Multiple Phase Operation in this chapter discusses multiphase calibration and operation.

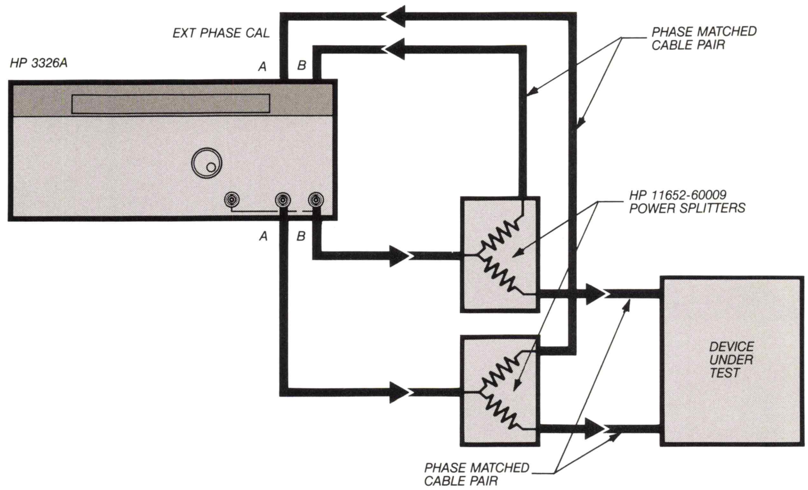


SELECT FUNCTION.



CALIBRATE.

Figure 5.2
External phase calibration connections.



TWO-PHASE MODE APPLICATIONS
SERVO SYSTEM STABILITY

Application
Accurate characterization of servo system stability used in electromechanical applications such as helicopter autopilots, bicycle ergometers and process control is needed to assure proper operation. Low frequency gain/loss and phase shift measurements are needed to characterize these servo systems. These low frequency measurements are also important in medical, geophysical and mechanical applications.

Measurement Considerations
The stability of a servo system can be determined using conventional techniques of measuring the magnitude and phase vs. frequency of the servo loop. The results can be plotted in several forms to characterize the servo system. A plot of phase versus magnitude on the complex s-plane is a Nyquist diagram. Log magnitude versus log frequency is a Bode plot. Plotting log magnitude versus phase yields a Nichols chart.

HP 3326A Solution
- **Phase Shift**

With the test setup shown in Figure 5.3, the HP 3326A is used to make accurate and simple phase shift measurements. This technique involves comparing the sinusoidal output of the device under test to the sinusoidal output of the HP 3326A Channel B signal, then adjusting the Channel B phase until a phase null is reached. The phase angle of the device under test is read directly from the HP 3326A Channel B phase display.

A phase null is indicated on an oscilloscope, configured in the X-Y mode. The X-Y mode produces a straight line Lissajous pattern, as shown in Figure 5.4.

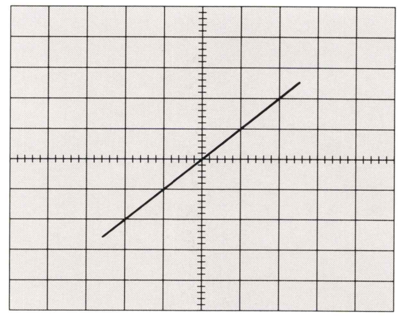
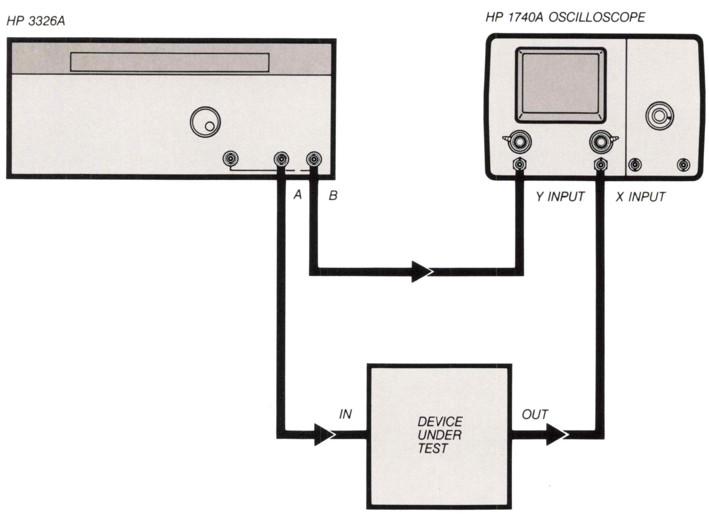


Figure 5.4
A phase null is indicated by a straight line on the oscilloscope display.

Figure 5.3
Setup for measuring phase shift using the Lissajous technique.



The null technique yields high phase sensitivity with excellent repeatability. By increasing the oscilloscope scaling factor, small changes can be observed near null. The accuracy of the phase shift measurement is limited by the HP 3326A phase accuracy, the depth of the null and the phase match of the X and Y oscilloscope inputs.

Normally at low frequencies small differences in cable lengths along the signal paths to the oscilloscope do not introduce significant phase errors. However, at RF frequencies, as in some electronic applications, the effects of different cable lengths should be considered. Errors can be minimized by using the HP 3326A's built-in internal or external phase calibration capability and is recommended before making a measurement.

• ***Gain/Loss***

To accurately determine the magnitude of the gain (or loss) in the servo loop, the HP 3326A's output attenuator can be used as a standard in a substitution measurement. Using this technique, the oscilloscope is placed in the normal time base mode, and the output of the servo loop under test is connected to the Y-axis input. Temporarily replace the servo loop under test with a through connection to establish a reference level on the oscilloscope, then note the HP 3326A Channel A output level. Now reconnect the device under test and adjust the HP 3326A Channel A output level for an oscilloscope display at the reference level. The difference between the reference level and the readjusted HP 3326A output level in dB is the servo loop gain at the test frequency.

TRACK-AND-HOLD SETTLING TIME

Application

Track-and-hold circuits are commonly used in analog-to-digital converters. Their design and performance evaluation often requires the measurement of settling time after a full scale input change. The characterictics of the amplifier in track-and-hold device usually determine settling time. A model of a typical track-and-hold circuit is shown in Figure 5.5. In this model, the amplifier input tracks the signal at all times and samples of the amplifier output are taken and held for various times after a full scale input change.

Measurement Considerations

The value of the sampled signal can be measured on a digital voltmeter for various delay times after a full scale track and hold circuit input level change. A test setup for this measurement is shown in Figure 5.6. In this setup, the gate signal is a particular logic level (e.g., TTL, ECL, CMOS, etc.) and the input level is rapidly changed between the device minimum and maximum values to simulate a full scale range change.

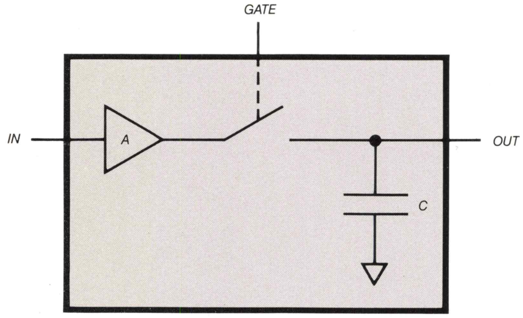


Figure 5.5
A block diagram of a typical track-and-hold circuit.

HP 3326A Solution

The HP 3326A Two-Phase mode with square wave output is used to generate both a rapidly changing input signal and the gate signal with a known delay time as shown in Figure 5.7. The HP 3326A Channel B dc offset and square wave amplitude are adjusted to the produce the required gate logic signal. This gate signal is also used to trigger the digital voltmeter which measures the sampled value. The delay time T is related to the HP 3326A Channel B phase offset $\Delta\phi$ as given by the equation $T = \Delta\phi/(360 \times \text{freq(Hz)})$.

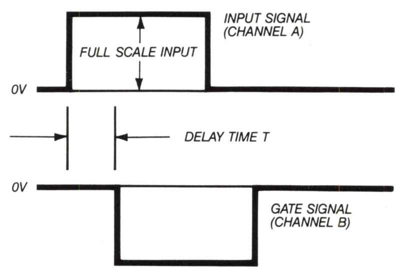


Figure 5.7
The HP 3326A Two-Phase mode is used to generate both the input and gating signals with an accurate delay time.

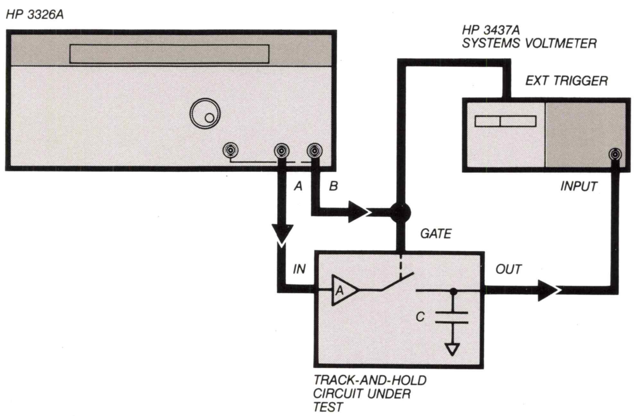


Figure 5.6
Track-and-hold settling time measurements can be made with this setup using an HP 3326A.

The HP 3326A performance allows precise delay times to be generated. The minimum delay is determined by the residual PM performance of the HP 3326A. Residual PM causes gate jitter of approximately 0.1 percent of a period (e.g., 1 ns at 1 MHz and 1 μs at 1 kHz). The rise/fall time of the HP 3326A square wave is approximately 15 ns.

The maximum delay time is two periods of the test frequency. By varying the delay time (Channel B phase) and taking a series of readings on the digital voltmeter the track and-hold settling characteristics can be measured as a function of time after a full scale input change. Figure 5.8 shows a settling time measurement using this procedure.

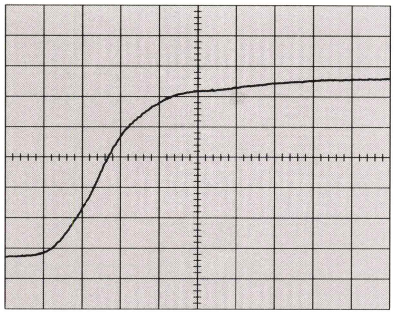


Figure 5.8
Example of a track-and-hold settling time measurement.

BALANCED OUTPUT

Application

A balanced output has two lines which are symmetical about ground, with equal signal levels and 180 degrees out of phase. Balanced outputs are used to drive balanced loads such as a balanced line used in high speed data transmission to remote terminals from a central computer. They are also used to drive symmetrical circuits such as switching regulators or amplifiers.

Measurement Considerations

Many of these applications requiring a balanced output can be driven directly with respect to ground. For those applications requiring a non-grounded reference point or floating balanced signals, balancing transformers are commonly used. Impedances such as 124, 135, 150, 300, 600 or 900 Ohms may also be required in these applications.

HP 3326A Solution

The HP 3326A can be used to produce two signals with a 180 degree phase relationship using the Two-Phase mode. The two signals can be set to equal levels and both are referenced to ground. The equivalent circuit for this is shown in Figure 5.9. Note that the output impedance is twice that of each HP 3326A output or 100 Ohms (without the High Voltage Output Option) and the Channel A and B levels are each one-half of the balanced output level.

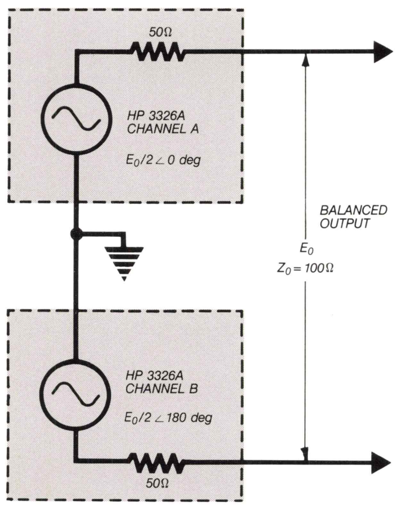


Figure 5.9
Equivalent circuit of the HP 3326A output when used as a balanced source.

For those applications requiring other impedances, it is a simple matter to add a balanced attenuator to the HP 3326A output as shown in Figure 5.10. The values for R1 and R2 are given by the following equations where ZS = 100 Ohms (HP 3326A balanced output impedance) and ZL is the load impedance.

$$R1 = ZS/\sqrt{1-ZS/ZL}$$

and

$$R2 = ZL/2\,\sqrt{1-ZS/ZL}$$

Values for R1 and R2 are listed in Table 5.1 for some of the common balanced output impedances. Attenuation values are also listed so that the HP 3326A output level can be increased to compensate for the loss in the attenuator pad.

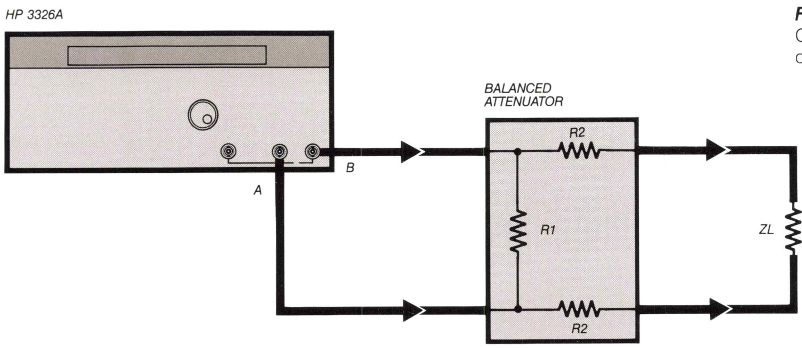


Figure 5.10
Output impedances other than 100 Ohms can be obtained using a balanced attenuator pad.

Impedance(ZL) (Ohms)	**R1 (Ohms)**	**R2 (Ohms)**	**Attenuation (dB)**
124	227.3	27.3	4.10 dB
135	196.4	34.4	4.88 dB
150	173.2	43.3	5.72 dB
300	122.5	122.5	9.96 dB
600	109.6	273.8	13.42 dB
900	106.1	424.3	15.31 dB

Table 5.1 Balanced attenuator values for various impedances.

PHASE DETECTOR TESTING

Application

A phase detector is an important component in phase-locked loops, communication systems and many other applications. The function of a phase detector is to produce an output signal that is proportional to the phase difference between its two input signals. An ideal phase detector has a linear transfer function between its output and input. Characterization of this transfer function is important in order to analyze overall system performance.

Phase Detector Measurement Considerations

The slope of a phase detector transfer function is a key factor in the loop gain of a phase locked loop. The distortion characterictics of a phase demodulator are related to detector linearity. The slope or linearity of the transfer function may vary over the detectors' input range.

Measurement of detector characteristics can be difficult because the non-linearity of interest frequently occurs over a small region such as the zero crossover point. A phase detector characteristic with a change in slope around zero phase is shown in Figure 5.13. Phase modulation techniques can be used to simplify the measurement of phase detector linearity and gain.

HP 3326A Solution

The HP 3326A is particularly useful for phase detector testing because it pro vides the required two input signals and can be phase modulated. In addition, it has the phase resolution and accuracy required and offers both sine wave and square wave signals for testing both analog and digital types of detectors. HP 3326A PM linearity is ± 0.5 percent of the best fit straight line over a ±360 degree range.

Figure 5.11
A typical phase detector transfer function. Vertical axis 100 mv/div.; horizontal axis 75 deg/div.

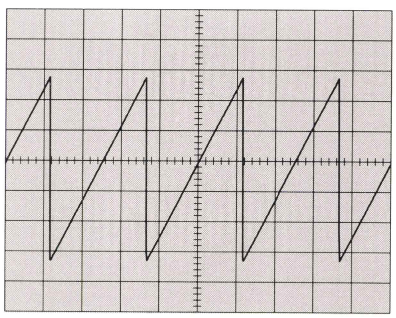


Figure 5.12 shows a test setup for measuring phase detector characteristics. Using the HP 3326A Two-Phase mode, Channel B phase is adjusted for operation at the detectors' region of interest. The HP 3326A Channel A and B output levels and waveforms are adjusted to be compatible with the phase detector input requirements.

The HP 3326A Channel A output is externally phase modulated with a sine wave (or triangular wave) from the HP 3314A Function Generator at a convenient rate below 5 kHz. This signal also drives the X-axis of the HP 1740A Oscilloscope. The phase detectors' output level versus input phase is displayed on the oscilloscope. Resolution can be increased by reducing the peak deviation and increasing the oscilloscope sensitivity. Figure 5.13 shows an example of a phase detector transfer function characteristic as measured with this technique.

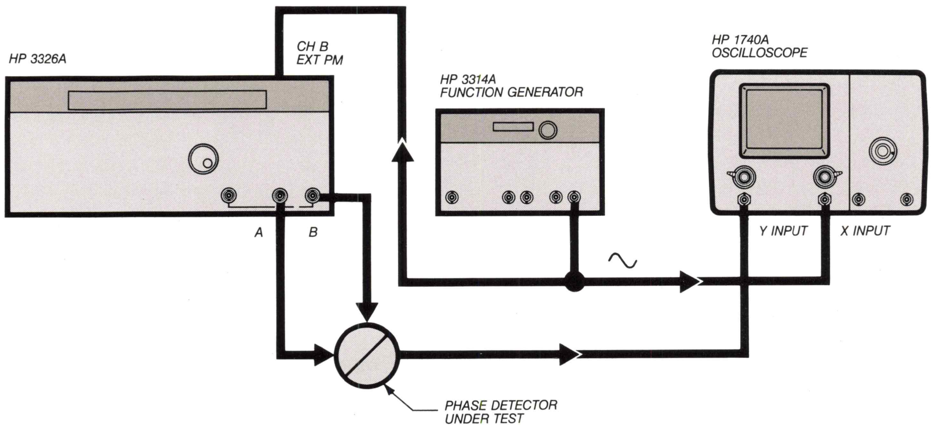


Figure 5.12
Setup for phase detector testing using the HP 3326A.

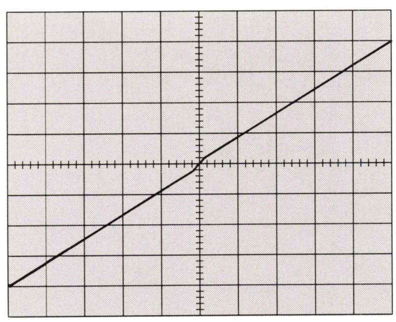


Figure 5.13
A digital phase detector response to input changes centered around zero phase. Vertical axis 50 mV/div.; Horizontal axis 10 deg/div.

PHASED ARRAY STEERING

Application

The directivity pattern of multiple-element phased arrays such as those used in sonar, medical ultrasound imaging and radio communications are usually steered in a particular direction. Steering allows the main lobe of the directivity pattern to be concentrated at an object or in a desired direction. This minimizes transmitter power requirements and maximizes the received signal level. Steering also reduces the effects of unwanted interference and is of particular important in pulse applications where it reduces the effects of echoes.

Directivity pattern steering can be accomplished by controlling the signal time delay between the individual transducer elements in the array as illustrated in Figure 5.14. The phase difference between the wavefronts at each array element is a function of the azimuth direction. By adding the proper time delay or phase offset to (or from) each element, the combined array can be made to constructively add signals in the desired direction or reject those in other directions.

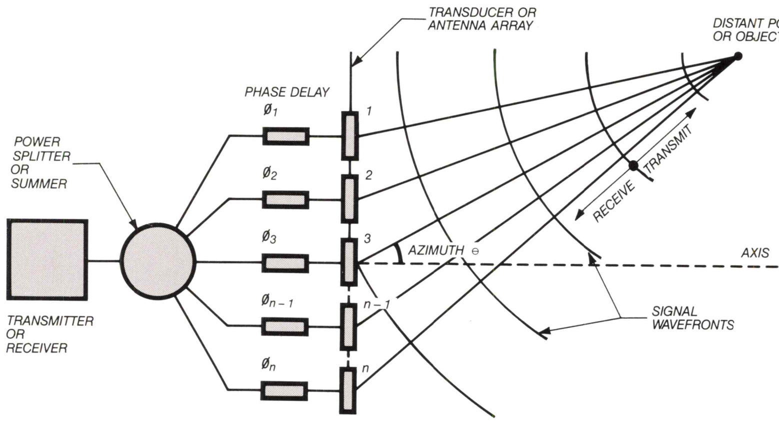
Measurement Considerations

The HP 3326A offers high resolution phase control that is needed in array steering applications. Two or more HP 3326A's can be used together to generate the required number of signals with an accurate phase relationship for multiple phase applications. The use of additional HP 3326A's does not require a phase meter or other instruments to maintain calibration. A built-in multiphase calibration function can be used to align the phase of these additional HP 3326A's to a reference phase. This subject is discussed in this chapter under Multiple Phase Operation.

HP 3326A Solution

The method of phase control varies depending upon the array design, but in general, consists of either controlling the phase at the operating frequency of the array, or controlling the phase of a local oscillator signal in a mixer scheme. Figures 5.15 and 5.16 are block diagrams of typical phasing schemes.

Figure 5.14
Operation of an electronically steerable phased array.



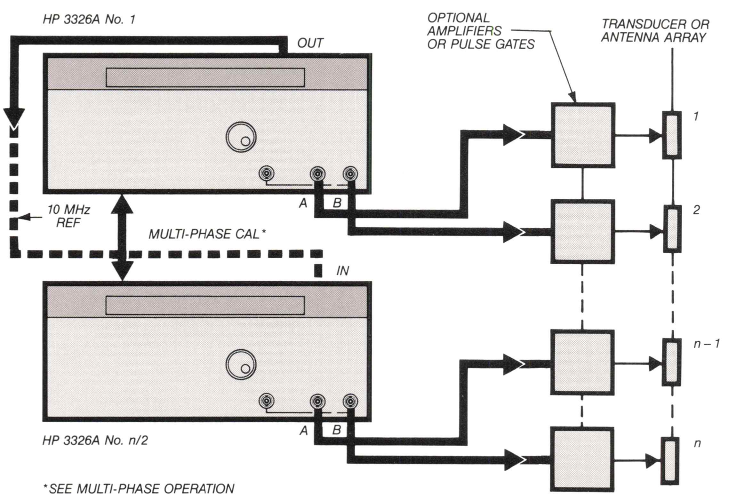


Figure 5.15
Each element of a phased array may be driven with the proper phase relationship from separate HP 3326A outputs.

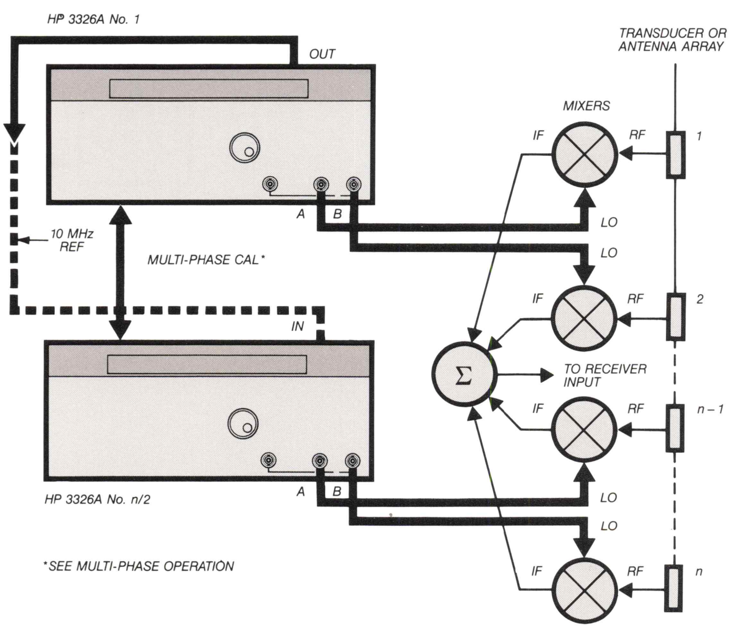


Figure 5.16
A mixer scheme can be used where the phase of the local oscillator is varied to steer or focus the array. The mixer outputs are summed and used as the receiver input.

MULTIPLE PHASE OPERATION

Application

Many applications require accurate phase relationships between more than two signals. Multiple single output sources with adjustable phase capability can be used to generate multiple phase signals. However, this usually requires additional instruments such as a phasemeter to set and maintain a calibrated phase relationship between the signals. The additional equipment can be expensive and complicates the measurement.

Measurement Considerations

Two or more HP 3326A's can be used together to simplify the multiple phase measurement problem in several ways. First, built-in multiphase calibration capability can be used to align the phase of one or more HP 3326A's to a reference phase. Once aligned, the phase of any output signal can be adjusted to the required offset without the need for additional instruments. Second, by providing two phase related signals in one instrument, the number of required source instruments is reduced.

Multiphase calibration is accomplished with two easy keystrokes. Use the Select key to select the Multiphase Calibration mode, then press the Manual key to initiate the calibration.

HP 3326A Solution

Suggested connection diagrams for three and four phase operation are shown in Figures 5.17 and 5.18, respectively. Additional phases can be added by further splitting reference Channel A output to provide calibration signals for more HP 3326A's until the calibration input level falls below +4 dBm (1 Vp-p). The use of two-resistor power splitters as shown in the figures with phase matched outputs is recommended for highest accuracy.

Three power splitters, with 6 dB loss each, will provide an external phase calibration input level of + 6 dBm at an HP 3326A output level of +24 dBm. With seven power splitters an additional seven HP 3326A's can be added for a total of sixteen phases. Additional phases can be added by using Channel A of each successive HP 3326A as another phase reference, with the appropriate power splitters.

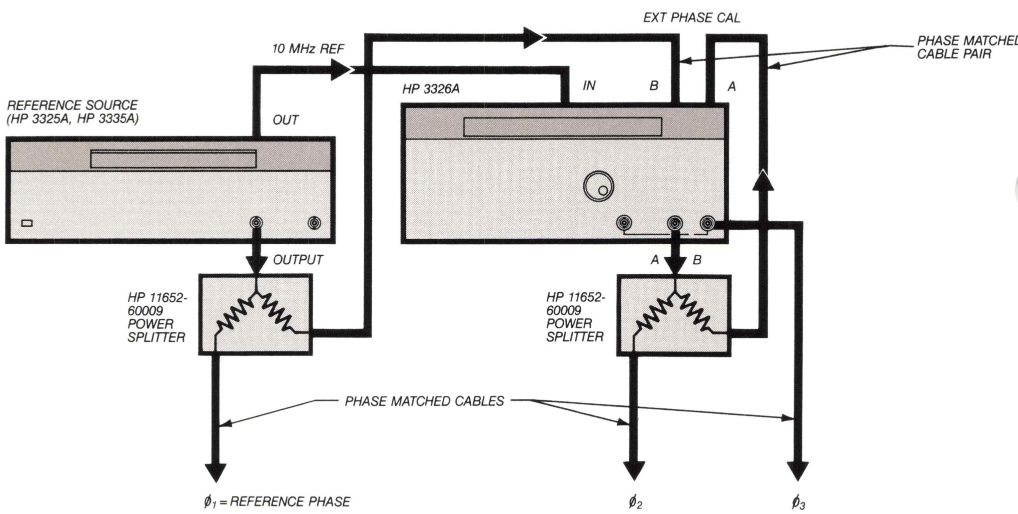


Figure 5.17
Setup for three-phase operation using the HP 3326A with another synthesizer.

The following rules must always be applied for accurate calibration. Significant errors beyond instrument accuracy can be introduced if these rules are not used:

1. The paths for the rear panel A and B external phase calibration inputs must be phase matched to each other for each HP 3326A. This rule also applies to the signal paths from each HP 3326A front panel output to the load. These paths may include one or more power splitters.

2. Calibration must be done with the same waveforms and equal signal levels ($\geq +4$ dBm or 1 Vpp) at the phase calibration inputs. User test levels may be different than the output levels required during calibration. In this case, the levels will have to be changed momentarily during calibration.

3. Calibration can be done only above 1 kHz, but is valid below 1 kHz if all sources are HP 3326A's and are triggered to change frequency simultaneously.

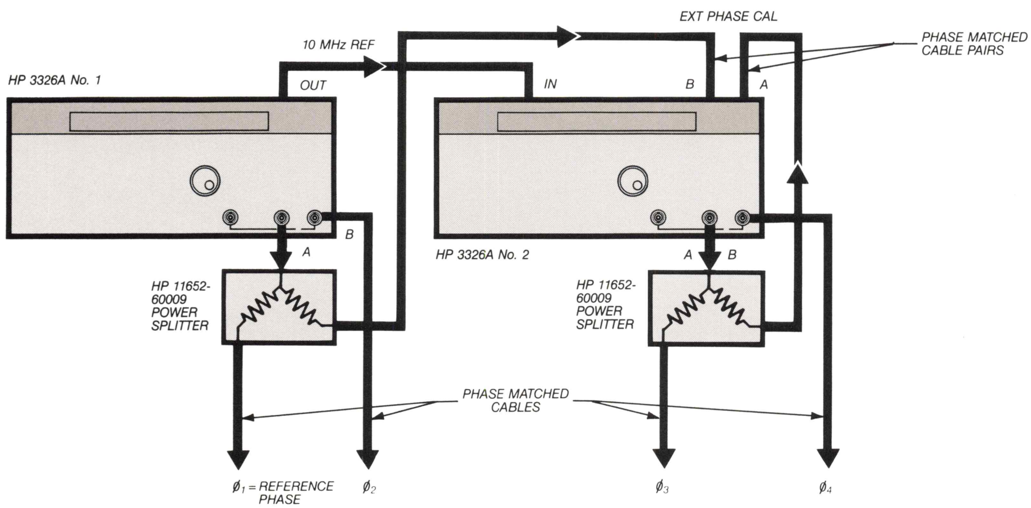


Figure 5.18
Setup for four-phase operation using a second HP 3326A.

APPENDIX A. ERROR MESSAGES

APPENDIX A. ERROR MESSAGES

This Appendix lists the error message and code set for the HP 3326A. A description of each error is given to assist the user in correcting a particular error condition. These error messages and codes are indicated on the HP 3326A display and the codes are available via the HP-IB. Errors are caused by either improper programming or instrument faults.

Message	***Code***	***Description***
SNTX	10	HP-IB command has syntax error or contains illegal characters.
RMOT	11	Front panel key pressed while HP 3326A in remote.
LOCK	12	LOCAL key pressed while HP 3326A in local lockout.
RNGE	20	Value entered for selected parameter exceeds valid limits.
RNGE	21	In 2 TONE mode, Channel B offset frequency greater than 100 kHz.
RNGE	23	Discrete frequency sweep element save nonsequential with existing elements, or instrument state save breaks continuity of discrete frequency elements.
RNGE	24	Marker frequency entered is outside sweep span.
RNGE	25	Frequency value greater than 1 MHz entered with high voltage option active.
RNGE	26	Frequency value greater than 5 kHz entered with internal PM active, or greater than 100 kHz with internal AM active.
B FR	30	In 2 TONE mode with Channel B high voltage option enabled, Channel B frequency cannot track change to Channel A frequency.
INTR	40	Value that cannot be displayed has been interrogated over the HP-IB.
RNGE	46	Internal modulation enabled and Channel B amplitude or offset selected as display value.
RNGE	47	Channel B phase selected as display value when PULSE mode enabled.
CNVT	50	Units conversion results in zero display value.
SUFX	60	Units key selected improper for parameter selected.
SUFX	65	High voltage option enabled and dBm selected as units.
INC	70	Increment value or units incompatible with displayed value.
AMPL	80	Combiner selected but not enabled because current amplitude value is too large.
MODL	86	Combiner selected but not enabled because Internal AM or PM is enabled.
MODE	87	Requested operation or function incompatible with mode selected.
FREQ	88	Internal PM selected with Channel B frequency greater than 5 kHz, or internal AM selected with Channel B frequency greater than 100 kHz.
CMBR	89	Combiner selected but not enabled because AM or PM enabled.
SWFR	90	Frequency sweep start and stop frequencies are equal for both channels.
DUTY	94	Pulse duty cycle too narrow for sweep range.
SWFR	95	High voltage option enabled and sweep frequency is greater than 1 MHz.
SWFR	96	Channel B frequency exceeds 5 kHz internal PM limit or 100 kHz internal AM limit during sweep.
RATE	100	Sweep rate less than 5 mHz/s or greater than 0.5 MHz/ms.
DSWP	110	No discrete frequency sweep elements exist for discrete frequency sweep.
DSWP	114	Frequency too high for duty cycle requested during discrete frequency sweep.
DSWP	115	High voltage option enabled and discrete frequency sweep element frequency exceeds 1 MHz.
DSWP	116	Channel B frequency exceeds the 5 kHz internal PM limit or 100 kHz internal AM limit during discrete frequency sweep.
DSWP	117	Discrete frequency elements in memory incompatible with selected mode.

Message	***Code***	***Description***
P OF	120	Cannot clear Channel A phase offset.
H V	130	High voltage option selected and not installed.
H V	136	Channel B high voltage option selected with internal modulation.
H V	138	High voltage option selected when frequency is greater than 1 MHz.
CSUM	140	A checksum error for recall, learn, or program operation.
CSUM	150	Current instrument configuration incompatible with recalled or programmed state.
CRPT	160	An error is detected in an instrument state recalled from memory and instrument state is replaced with preset state.
A OL	170	Channel A output is overloaded.
B OL	171	Channel B output is overloaded.
SYOL	172	SYNC output is overloaded.
AVCO	173	Channel A voltage controlled oscillator is unlocked.
XREF	180	HP 3326A cannot lock to external reference signal that is present.
MCAL	190	Unsuccessful internal AM or PM calibration.
PCAL	191	Unsuccessful phase calibration.
ACAL	192	Unsuccessful amplitude calibration.
OCAL	193	Unsuccessful dc offset calibration.
	194	Unsuccessful residual dc offset calibration.
PASS	–	Successful self test.
FAIL	–	Unsuccessful self test.

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